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CALIBRATION COEFFICIENT USE AND VALUE
SELECTION GUIDANCE FOR THE MOSCOW
LAND COMBAT MODEL

by

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This thesis analyzes the use of calibration coefficient inputs for the Method of Screening Concepts of Operational Warfare (MOSCOW) model. The analysis focuses on how calibration coefficients affect modeled combat processes. Sensitivity analysis is performed to determine the effect of coefficient value changes on selected MOSCOW measures of effectiveness. A detailed description of each coefficient, including recommended input value ranges, is provided. The thesis provides information useful for effective calibration coefficient input value selection.

C.1

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Dr. Sam Parry introduced me to combat modelling and rendered experienced insight during my efforts to grasp the fundamentals of Lanchester force-on-force attrition laws. CPT Jim Hoffman spent a great deal of his own time focusing my attention on the pertinent details of MOSCOW's underlying concepts.

Dr. Philip J. Romero, MOSCOW's author, patiently endured numerous telephone conversations, and candidly answered countless questions about the model. He provided background information which was invaluable to my understanding of MOSCOW. I also wish to thank Margaret Campbell for her special efforts to place this thesis in its final form.

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I. INTRODUCTION

A. ORIGIN OF THE MODEL

Throughout history progress in the art of warfare has evolved through the development of new weapons and equipment (technology), and the selected method by which to employ them: the war fighting concept (doctrine). Ideally, doctrinal development is pursued in a manner which takes advantage of new or emerging technologies. Current era technological acceleration can create problems for those who decide on military organizations and doctrine, particularly when new "products" are presented and finding the "means to employ them" becomes the overriding factor in doctrinal development. The U.S. Army, recognizing that a warfighting concept and technology must interact harmoniously to maximize military potential, developed the Concept Based Requirements System (CBRS). This system emphasizes that a robust warfighting concept, developed considering future technologies and military resources, should set requirements for Army training, organizational structure, and acquired weapon systems. A robust concept is one which efficiently achieves campaign success over a wide range of scenario types.

The "Future Warfighting Concepts and Technologies" project is sponsored by the Army as part of the Applied Technology Program at Rand Corporation's Arroyo Center. The design of

this project is to develop improved methods for finding appropriate warfighting concepts and methods for forecasting the technical capacities of future weapon systems.

One of the products of this project is a warfighting concept screening tool called MOSCOW (Method of Screening Concepts of Operational Warfare). The intended purpose of MOSCOW is to perform inexpensive "first cut" concept screening. This tool is designed to quantitatively assess the effectiveness of a warfighting concept using relevant measures of effectiveness (MOE). Some MOSCOW MOE include number of friendly units required to win the campaign, personnel casualty figures, supplies consumed, and time enemy takes to penetrate given distances into the friendly zone. Because it is easy to use, MOSCOW can quickly generate measures to compare a large number of concepts over a wide range of scenarios with few resources. Potentially viable concepts that appear robust during MOSCOW analysis may then be selected for more exhaustive (and expensive) testing by other methods.

B. MODEL STRUCTURE

Moscow is a spreadsheet based (Lotus 1-2-3), low resolution combat model [Ref. 1:pp. 1-5]. It employs a Lanchester square law attrition module and emphasizes a cycle of activities for each unit between engagement events. The activity cycle represents the model author's premise that actual engagements form only a portion of a campaign fighting

process. Military forces engage in battles, but must undergo other activities between battles to sustain themselves throughout a campaign. The model is unique in its prescriptive approach. Conventional combat models determine the results of battles or the amount of "success" achievable based upon a set of inputs which describe the characteristics of opposing forces, and the conditions under which battle is joined. Moscow uses these inputs to determine the number of friendly maneuver units and resources required to achieve the required friendly force success conditions. Moscow inputs are organized into six categories.

1. Terrain Features.
2. Campaign Zone and Red Threat Scenario.
3. Blue Success Criteria and Threaten Level Policy.
4. Maneuver Unit Description (Unit Capabilities and Warfighting Concept).
5. Calibration Coefficients.
6. Proportional Constraints on Maneuver Unit Activities.

A substantial set of measures of effectiveness (MOE) is output for comparison between model runs. MOE comparisons form the basis for analysts to rank order potential warfighting concepts.

Moscow determines how a warfighting concept affects the results of a campaign, where large numbers of maneuver forces engage in numerous battles for some period of time. Each opposing force may assign subordinate maneuver units attack

and defend missions. Both attack and defend units spend time and exhaust resources passing through a cycle of activities between engagement events. The use of the activity cycle is intended to represent those intermediate processes, rest, repair, load supplies, etc. that a force must perform to sustain the ability to successfully engage in campaign attrition battles. The time spent in each activity between each battle is determined by the set of inputs which describes basic maneuver unit capabilities and the concept of warfighting under evaluation. A campaign consists of the number of cycles required to achieve input success conditions. Therefore the total time spent in each activity during the course of a campaign forms a distribution of activity times reported by MOSCOW.

Warfighting concepts can be compared based upon their relative efficiency in terms of numbers of maneuver units and resources required to obtain friendly campaign success. Each activity in the cycle consumes resources at some specified rate. Therefore a concept analyst can use the distribution of activity times to learn how competing warfighting concepts achieve success. Concepts may then be modified to achieve success in a manner acceptable to decision makers.

C. THESIS OBJECTIVE

The objective of this research is to provide information that will allow intelligent calibration coefficient selection

by potential users of MOSCOW. The required information is not provided by the model's existing documentation. The objective is achieved by performing analysis of the model's use of calibration coefficients. The result is a document to which users may refer to obtain information for choosing specific values for each coefficient and the potential effect it may have on model results.

D. THESIS SCOPE

Analysis is oriented on one category of MOSCOW's input section: calibration coefficients. Users should refer to References 1-4 for additional information about the MOSCOW model. The methodology used during analysis is described in Chapter III. It includes a verification of the model code pertaining to calibration coefficients. Code corrections were made as required to ensure that combat processes are represented as intended by the model's author or to enhance realism. The use of each calibration coefficient is explained to prompt considerations which should be made when selecting their value. A recommended range from which to select specific values is listed for each coefficient. The sensitivity of selected model outputs to calibration coefficient value changes within the recommended range is determined by a factorial experimental design.

II. ANALYSIS MOTIVATION

A. PREVIOUS WORK PERFORMED ON MOSCOW

References 1 and 2 were published by Rand Corporation to assist users of the Moscow model. The first publication provides extensive theoretical background on the model's development. It establishes the model's intended purpose as a warfighting concept screening tool within the context of CBRS. The document is a detailed account of the model structure. Examples are included which emphasize how MOSCOW can represent various warfighting concepts. It also includes an organized explanation of MOSCOW's strengths and weaknesses for representing different attributes of the combat process. Reference 1 also clearly explains MOSCOW's cycle of activity approach and devotes an appendix to describe the Lanchester attrition module.

The six input categories described earlier are addressed by both Rand publications. Many individual inputs are addressed in detail to guide potential model users. However, large input sections are addressed only as a group, without explaining considerations for selecting individual values. Reference 2 is actually an embellishment of the inputs description section of Reference 1. Almost all of the inputs are addressed by a short sentence to clarify their definition.

However two of the input categories are not addressed in enough detail to make intelligent input value selections.

The first category requiring additional guidance is that of "Maneuver Unit Description." This section includes all of the information concerning the capability attributes for both Red and Blue forces. This category also includes most of the inputs which describe the "concept" or warfighting style to be represented during model execution. Model users are not given enough information to understand how many of these inputs are used in the model. Without this information a user must make assumptions about the use of the inputs. When the assumptions prove incorrect, the result is that the actual "concept" intended for evaluation is not the one represented in the model. The consequences of this lack of information are misleading results and poor analysis.

Hoffman, recognizing the need for additional guidance, wrote a technical memorandum providing one methodology for the selection of MOSCOW inputs in categories two, three, and four [Ref. 3]. It explains one method for selecting a set of inputs which will reflect the desired "concept" of interest. Hoffman also directed his thesis effort towards identifying the fundamental assumptions upon which MOSCOW is based [Ref. 4]. The work contains extensive analysis of the model output sensitivity to changes in these inputs from base case examples.

Thorough study of the Rand publications and Hoffman's work provides MOSCOW users a foundation adequate to begin using the model with the exception of the calibration coefficient input category. This thesis is an effort to provide the remaining required information to perform intelligent input selection to properly use MOSCOW as an analysis tool.

B. THE NEED FOR CALIBRATION COEFFICIENT ANALYSIS

As with any new model there is little real user experience from which to learn MOSCOW's proper use or become aware of inherent shortcomings. The model is an analysis tool. The quality of any analysis using model results depends directly upon how well the model represents the actual behavior of the system under study. The analysis of calibration coefficient use in MOSCOW supports the following three factors which influence how well a model represents the system of interest:

1. Verification and validation processes are designed to ensure a model performs as intended by its originator. These processes include a wide range of tasks from simple code debugging to more complex issues such as ensuring that the model's level of resolution is appropriate for the modelled phenomenon.

2. The model must be used for its intended purpose. A highly aggregated model focusing on force sustainability should not be used to analyze the effects of some new weapon system on the result of a high resolution battle. Proper use is ensured by thoroughly understanding a model's internal processes and the discipline to apply it only to systems adequately represented. Ignorance of a model's internal processes can easily lead to misapplication.

3. The set of model inputs must accurately reflect the state of all elements of interest in the system represented. This includes simple notions such as

firing rates, to more complex input sets that describe the "operational warfighting style" of the force.

MOSCOW employs nine mandatory and 20 optional calibration coefficients. A few of these coefficients are addressed individually throughout Rand Reference 1. For the remainder, users can rely only upon a few paragraphs describing the purpose of this input set. These coefficients are predominantly used to affect the degree to which other inputs affect some intermediate model process. These intermediate processes include the times determined for several activities, the lethality and vulnerability of forces, frontage used during engagements, the effects of rest on mobility, and many others.

Consider having the following information with which to select the value of some calibration coefficient. The input name is IERRCOEFSURVTM. It affects the time of the survey and reconnaissance activity and subsequently the total cycle time between engagements. The other input involved is percent intelligence error with the relationship (1 + INTELLIGENCE ERROR)^IERRCOEFSURVTM. A previous example used a value of -100.00 for this coefficient.

Questions immediately arise concerning the considerations when selecting a value for IERRCOEFSURVTM. How sensitive is the time of the activity to this input? Can the input be positive? What does the complete time of activity equation look like, and are the units minutes, hours, or days?

As it turns out, analyzing the use of IERRCOEFSURVTM reveals important information. The actual equation for each cycle's time for the survey and reconnaissance activity is:

$$\text{TIME SURVEY \& RECON [DAYS]} = (1 + \%\ \text{INTELLIGENCE ERROR})^{\text{IERRCOEFSURVTM}}.$$

This activity represents the time to locate the opposing force between engagement events. Friendly intelligence error is a small value between zero and one, probably around .10. A plot of this function in Figure 1 demonstrates that using a negative calibration coefficient results in an unreasonable "trend." As a unit's intelligence error increases the time to locate the opposing force decreases. Common sense

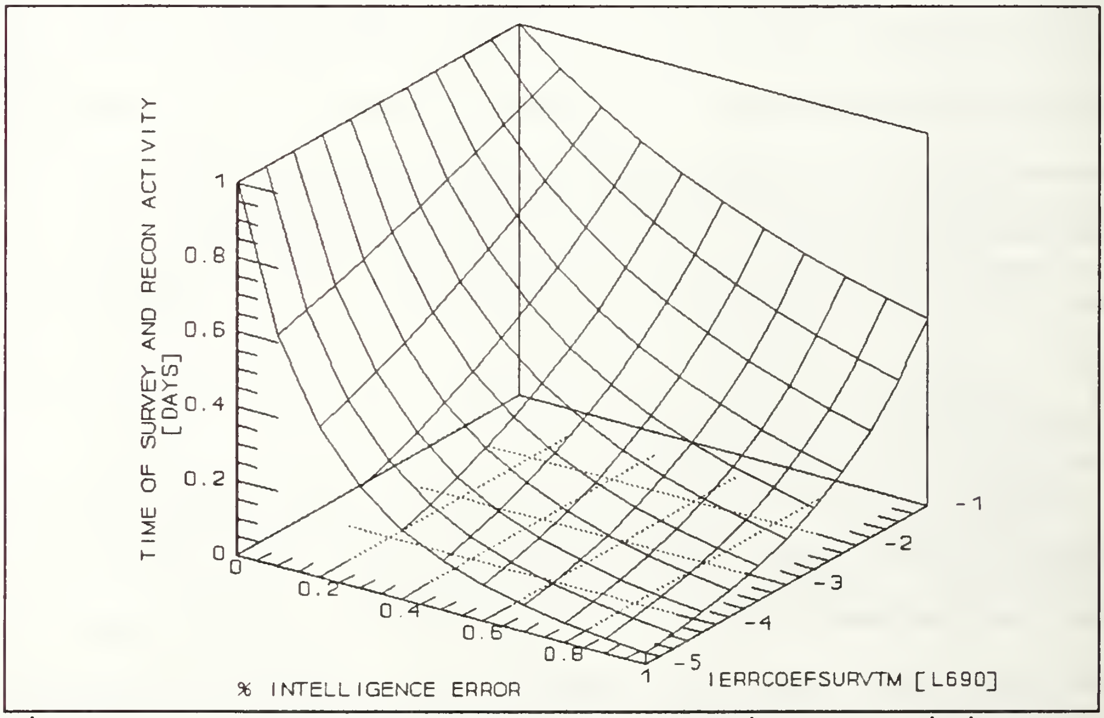

Figure 1. Example of Improper Trend in An Activity Due to Poor Calibration Coefficient Selection.

indicates this trend should be reversed. Using a positive calibration coefficient indicates that the minimum time to locate the opposing force between engagements is one day. This does not appear to be very flexible and unreasonable for many circumstances. Obviously there is a problem with the argument (1 + % intelligence error) since neither a positive or negative value for IERRCOEFSURVTM appears satisfactory. If we change the equation to:

$$\text{TIME SURVEY \& RECON [DAYS]} = 1 - (1 - \text{\% INTELLIGENCE ERROR})^{\text{IERRCOEFSURVTM}}$$

and replot it in Figure 2, the "trend" becomes reasonable for positive values of IERRCOEFSURVTM. As intelligence error increases, the time to locate the opposing force also increases. The sensitivity of the activity time to the percent intelligence error is determined by the magnitude of the IERRCOEFSURVTM coefficient. In this case a value of one implies a direct, linear relationship between intelligence error percentage and the time to locate the enemy. A coefficient greater than one implies a stronger effect while a value between zero and one implies a weaker effect of % intelligence error at the activity time. Note that the calibration coefficient must be greater than or equal to zero or an unreasonable negative activity time will result.

The analysis of this coefficient answered each question raised by the inadequate pre-analysis information. In addition, the model verification process became a by-product

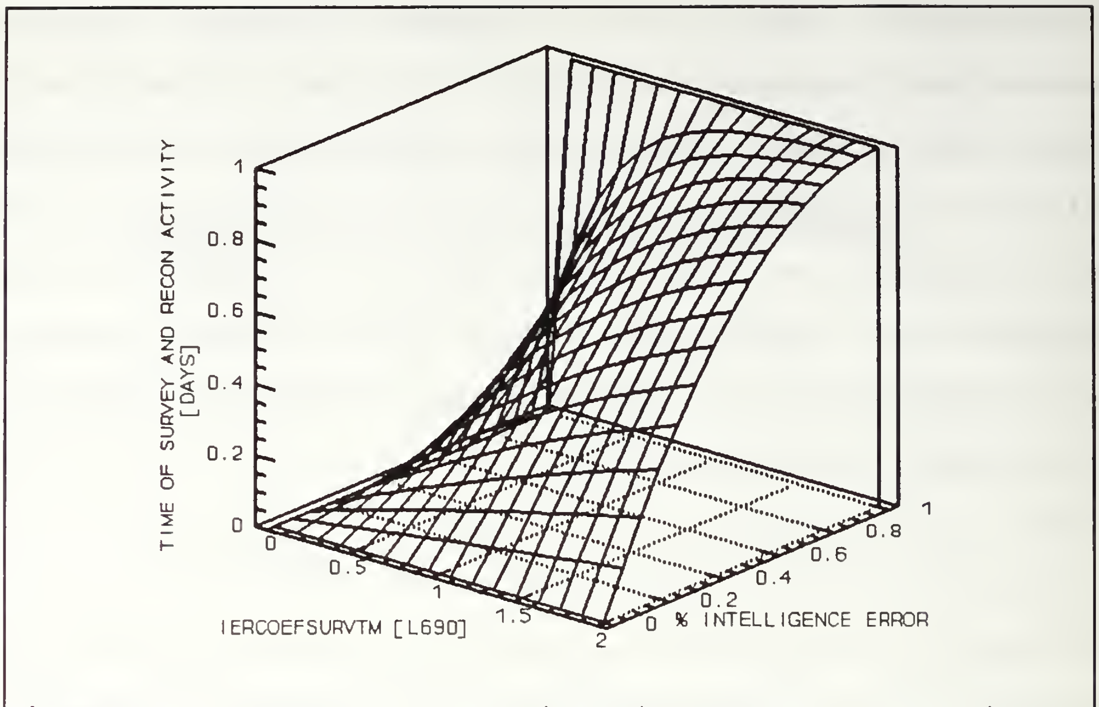

Figure 2. Corrected Relationship Between Intelligence Error, Coefficient L690, and Time of Survey and Reconnaissance Activity.

of the analysis. An improper "trend" was corrected to meet our expectation that an increase in intelligence error should lead to an increase in the time of the survey and reconnaissance activity. The information provided by the analysis should enable a model user to select an appropriate value for the calibration coefficient IERRCOEFSURVTM. The degree of sensitivity of the activity time may now be selected according to the user's needs.

The methodology used to perform similar analysis of the entire set of calibration coefficients is discussed in the next chapter. MOSCOW documentation does not provide enough

information for a user to simply determine this information in a timely fashion. Each coefficient generally affects two to eight or more equations in various locations in the spreadsheet code. Graphical analysis of these equations is the only efficient way to detect improper trends such as that just discovered in the aforementioned example. In other cases the influence of a coefficient on a modelled process is more complicated and typically involves analyzing several subsequent modules of the spreadsheet to determine its effect. By performing this analysis, making corrections as required, and documenting the results, model users will have a ready reference for intelligently selecting appropriate values for this set of inputs. A by-product of the analysis is that a number of intermediate processes in the model more accurately reflect actual combat processes.

III. ANALYSIS METHODOLOGY

A. OVERVIEW

The methodology used during calibration coefficient analysis is divided into six steps. The procedures are intended to form a systematic framework from which consistent analysis may be completed for all 29 coefficients. MOSCOW'S code is not well documented to facilitate verification analysis by virtue of its spreadsheet format. However, the model author constructed the spreadsheet in a well organized fashion. The spreadsheet is divided into eight "screen wide" columns called modules. Each module is partitioned by subsections called tables, each pertaining to some particular process or related topic. Executing the analysis is therefore a tedious, but manageable task. Each step of the methodology is explained below using an example calibration coefficient.

Information determined by this methodology is summarized for each calibration coefficient in Appendix B. Appendix B is perhaps the most important part of this work. It contains the information MOSCOW users should consult when selecting calibration coefficient values.

Coefficient names used in this document are the same as used in MOSCOW to provide easy cross reference to the model. The calibration coefficient used to illustrate the methodology procedural steps is named DISMTDLETHCOEF. This calibration

coefficient modifies force lethality as a function of the percentage of infantry that is conducting dismounted operations. MOSCOW explicitly models only one "average" type of combat vehicle and its corresponding "average[1]" weapon system. However, the model employs techniques which attempt to capture various combat sub-processes. In this case a lethality modification exists to capture the effect of employing different levels of dismounted infantry.

B. PROCEDURAL STEPS USED DURING ANALYSIS

1. Determine Where the Coefficient is Used in the Model

The model spreadsheet is searched to determine each line of code using the calibration coefficient. This step is performed by using a printout of all spreadsheet cell formulas, and manually searching each line of code.

For example, documentation indicates that DISMTDLETHCOEF is used to modify force lethality. A search finds that the coefficient is used in two tables (LETHALITY CALCULATIONS C.5 AND C.6) within the Intermediate Calculations module in a total of twelve cell formulas. The spreadsheet is checked in its entirety to ensure these are the only formulas which employ this coefficient.

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[1]MOSCOW requires the user to aggregate all modelled weapon systems into an "average" weapon system since the attrition module is based upon homogeneous Lanchester square law equations. Model users are left to determine their own aggregation methods. Reference 3 is devoted solely to one methodology for aggregating unit weapon systems.

2. Determine the Sub-process Affected By the Coefficient

Each calibration coefficient affects some specific process represented in the model. The total combination of all sub-processes forms MOSCOW's representation of the larger Campaign process. The terms process and sub-process are used interchangeably in this paper when referring to the smaller process which combine to form the Campaign process. Contextual use will clarify the term's intended meaning. Some of these processes include activity times, mobility, lethality, maneuver frontage, vulnerability, and security force requirements. Studying the tables where each coefficient is used provides information about how MOSCOW models a particular process.

The tables which use DISMTDLETHCOEF compute the Lanchester lethality coefficients subsequently used by the attrition module for attack and defend engagements. In these tables, other inputs are used to determine the following initial "naive" estimates for both Red and Blue lethality.

$$\frac{\text{HITS}}{\text{MIN}}\,1 = \frac{\text{SHOTS}}{\text{MIN}} \times \frac{P_{\text{HIT}}}{\text{SHOT}} \quad \text{(on enemy vehicles)} \tag{1}$$

$$\frac{\text{KILLS}}{\text{MIN}}\,1 = \frac{\text{HITS}}{\text{MIN}}\,1 \times \frac{P_{\text{KILL}}}{\text{HIT}} \quad \text{(on enemy vehicles)} \tag{2}$$

$$\frac{\text{PHITS}}{\text{MIN}}\,1 = \frac{\text{HITS}}{\text{MIN}}\,1 \times (\text{ANTI-PERSCOEF}) \quad \text{(kills on enemy personnel)} \tag{3}$$

where anti-personnel coefficient is an input used to determine the number of personnel kills per vehicle kill.

These "first iteration" estimates (signified by the number 1 used in the equation) are modified three times based upon such influences as terrain, target availability, amount of rest, and command, control and communications (C3) error. After these three modification steps the result [KILLS 4/MINUTE] is used in the Lanchester attrition module. [HITS 4/MINUTE] values are used to generate dismounted personnel losses.

DISMTDLETHCOEF is used in the last modification step as follows:

$$\frac{HITS}{MIN}\,4 = \frac{HITS}{MIN}\,3 \times (\%\ \text{Personnel Dismounted})^{DISMTDLETHCOEF} \tag{4}$$

$$\frac{KILLS}{MIN}\,4 = \frac{KILLS}{MIN}\,3 \times (\%\ \text{Personnel Dismounted})^{DISMTDLETHCOEF} \tag{5}$$

$$\frac{PHITS}{MIN}\,3 = \frac{PHITS}{MIN}\,3 \times (\%\ \text{Personnel Dismounted})^{DISMTDLETHCOEF} \tag{6}$$

There are corresponding equations for Red and Blue forces in both attack and defend activity tables for a total of twelve cell formulas using this coefficient.

3. <u>Study Process Relationships</u>

Steps one and two provide the information necessary to study the effect of the coefficient on the process involved. The form of cell formulas, and their subsequent use, define these effects. Analysis at this level verifies that MOSCOW code matches intuition and the author's intent concerning process conduct. This step provides the

information necessary to establish reasonable ranges for calibration coefficient values.

The process involved for the example is the effect of dismounted infantry on force lethality. The idea is that a force has some inherent lethality prior to dismounting some portion of its infantry [Ref. 1]. This lethality will increase by some amount as more infantry is dismounted since more firers will increase the force kill rate. The degree to which dismounted infantry modifies the kill rate is determined by the calibration coefficient DISMTDLETHCOEF. Figure 3 is a surface plot of the force kill rate (Equation 5 above) for different levels of percent infantry dismounted and the

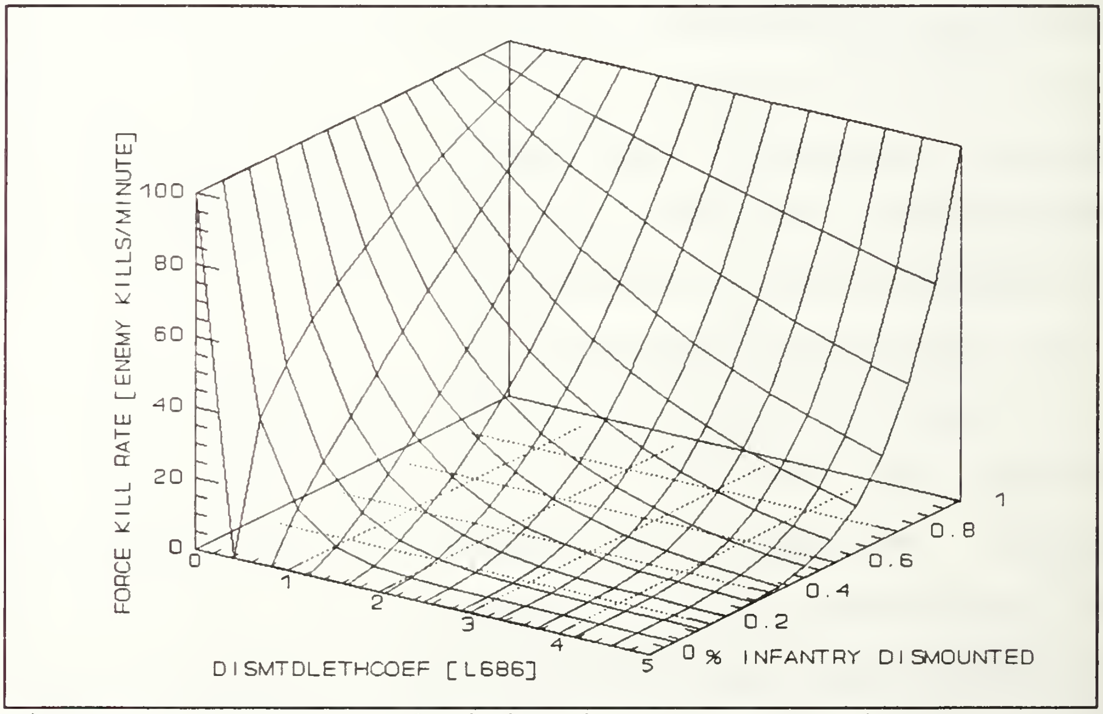

Figure 3. Improper Modification of Force Kill Rate Due to Dismounted Infantry.

coefficient DISMTDLETHCOEF. The pre-dismounted infantry kill rate is set at 100 kills/minute in the figure for purposes of example. The figure shows that Equation (5) does not model this process as the author intended. The force kill rate before considering dismounted infantry is 100 kills/minute. Equation (5) actually reduces this kill rate by some fraction corresponding to the percentage of dismounted infantry. Only if all infantry is dismounted is force lethality maintained at 100 kills/minute. Since the kill rate increases as dismounted infantry increases, the trend is appropriate, but it should increase from 100 kills/minute, not zero.

If a negative value for DISMTDLETHCOEF is used the trend would inappropriately reverse. Unreasonably high increases in the kill rate would occur at small percentages of dismounted infantry, while full dismounting would leave the kill rate unchanged. Obviously Equation (5) requires modification to reflect the authors intent and intuitive belief about this process.

A feasible modification of Equation (5) is:

$$\frac{\text{KILLS}}{\text{MIN}} 4 = \frac{\text{KILLS}}{\text{MIN}} 3 \times (1 + \%\ \text{Personnel Dismounted})^{\text{DISMTDLETHCOEF}} \qquad (7)$$

which is plotted in Figure 4. This simple code correction retains the appropriate trend and increases the pre-existing kill rate as infantry dismounts. The degree to which dismounted infantry increases force lethality depends upon the value selected for DISMTDLETHCOEF.

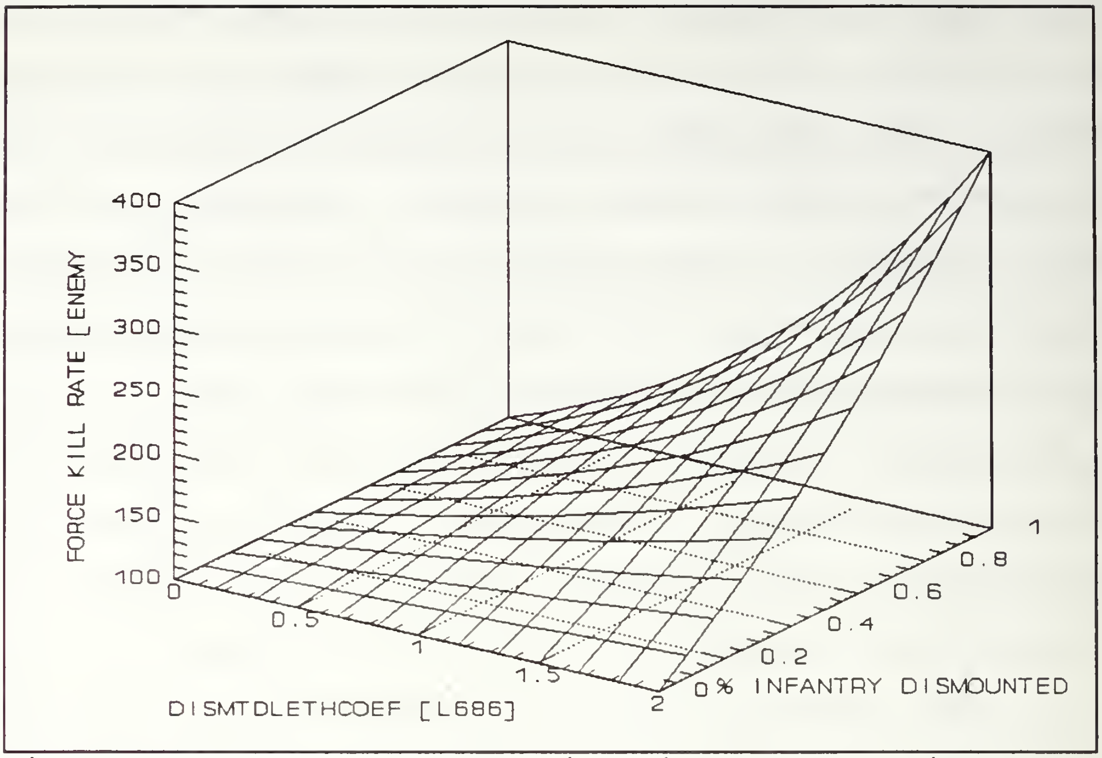

Figure 4. Corrected Relationship Between Dismounted Infantry and Force Kill Rate.

Many equations using calibration coefficients required modifications in order to correct improper trends or other problems. When modifications to MOSCOW were required a feasible alternative was recoded into the model. A list of code corrections appears in Appendix C. The recoding was performed so that subsequent sensitivity analysis was not rendered invalid by processes which were obviously misrepresented. More value is realized by correcting deficiencies than simply reporting their existence. The

modified version of this model, labeled MOSCOW-NPS, was used during sensitivity analysis.

4. Determine the Calibration Coefficient Value Range

Information gathered in previous steps is used to determine the set of values from which model users should select specific calibration coefficient values. Effort to this point has been preliminary to ensure that the effect of the calibration coefficient on some specific process is well understood and corrected if necessary to meet intuitive trends. In this step the value range consists only of those calibration coefficient values which return reasonable sub-process results. The word reasonable is used because there is no formula or recipe for establishing decision rules to select the range. There are many combat sub-processes which the model attempts to capture. Sub-process results vary in actual combat just as different input values render various sub-process results in the model. The intent is to establish a set of calibration coefficient value ranges for which the model will return sub-process results that are within reasonable bounds one may expect in a campaign. For example, MOSCOW models the degrading effects due to lack of rest. Two inputs, BASELINE % REST, and % REST combine to determine the fraction of required rest units get in the campaign. Lack of rest slows unit movement and lethality. The value selected for the calibration coefficient LOWRESTCOEF determines the degree by which movement and lethality are degraded by the

lack of rest. This analysis shows that LOWRESTCOEF values much greater than five can reduce movement and lethality to almost zero, even when units get most of the required rest. Certainly lack of rest has degrading effects, but when a model user selects large values for this coefficient this effect is severely overemphasized.

One cannot place much confidence in a model which grossly misrepresents fundamental combat sub-processes. The idea is that more confidence will be placed in the results of a model which reasonably represents fundamental combat processes.

The plots produced in step three are evaluated using reasonableness as the decision rule to select calibration coefficient value ranges. For example, Figure 4 is used to determine which values for DISMTDLETHCOEF return a reasonable modification of force kill rate by dismounting infantry. When no infantry is dismounted the previous kill rate should remain the same. A value of zero for DISMTDLETHCOEF in Figure 4 fulfills this requirement. The value zero becomes the lower bound for DISMTDLETHCOEF's range of values. Note that whenever zero is used for this coefficient the user is implicitly assuming that dismounted infantry has no effect on the force kill rate.

The question is, considering campaign averages, how much can a force commander expect to increase his average kill rate when dismounting infantry? In reality, higher level

commanders perform no such analysis. The reality is that dismounted infantry and platform mounted weapons are complimentary resources. The amount of dismounted infantry and its relative lethality fluctuate in response to ever changing small unit situations. The decision to dismount is made at the small unit level only when and where the situation makes this tactic relatively advantageous. Therefore campaign success may more appropriately depend upon the availability of dismounted infantry in many small unit situations throughout the campaign.

Since low resolution models such as MOSCOW do not capture evolving small unit situations, one must resort to "average effects." When forced to quantify such an ambiguous average it is reasonable to expect that a combat force, on average, would at most double its lethality by dismounting infantry. Therefore, doubling the force kill rate is selected as an optimistic upper bound. Using Figure 4, this implies a corresponding upper bound of one for DISMTDLETHCOEF's value range. The actual DISMTDLETHCOEF value for most campaign scenarios should be between zero and one.

5. Conduct Sensitivity Analysis

Once calibration coefficient reasonable ranges are determined, the next question becomes "What is the effect of choosing particular calibration coefficient values on model results?" The calibration coefficient value ranges were determined based on a reasonableness rule of thumb pertaining

to corresponding process results. The purpose of this step is to determine how sensitive MOSCOW's overall MOE are to changes in calibration coefficient values. The MOE results are determined by the manner in which the model represents the cumulative effect of a full set of inputs. These MOE are used to compare and rank alternative "concepts" over a range of scenarios to determine which are promising enough to continue analysis by more exhaustive methods. It is important to determine if MOE results are overly dependent upon particular model inputs. Work by Hoffman examined this dependence in detail for most MOSCOW inputs, but did not include calibration coefficients [Ref. 3].

An assumption made about the overall combat process, is that, given some state of equilibrium in combat, a small change in sub-process states or entity attributes should not elicit large changes in combat outcomes. Considering the enormous number of sub-processes which comprise the overall combat process, this assumption is intuitively appealing. Therefore, combat model results, in general, should not be overly sensitive or dependent on any particular sub-process. Conversely, model results should not be totally insensitive to change in these sub-processes. If either case occurs, the model may not accurately reflect the manner in which actual combat sub-processes combine to determine actual results. The complexity involved in validating MOSCOW's ability to represent actual combat results is beyond the scope of this

paper. Such analysis should be performed by a team of analysts possessing a broader knowledge and access to other combat models and historical data. This paper essentially reports the sensitivity of MOSCOW MOE to changes in calibration coefficient value ranges determined in step 4.

A 2^k Factorial experiment is the method used to perform the sensitivity analysis. The method was selected because it has important advantages over a "one variable at a time" approach. This factorial method requires a model run for two different values (levels) for each of "K" calibration coefficients (factors). These 2^k model runs are required to record MOE values for each combination of the "K" calibration coefficient's two levels. The "main effect" of a calibration coefficient on an MOE is the difference between the average MOE value for all runs when the calibration coefficient is at "high" level, and the average for the MOE value for all runs when the calibration coefficient is at a "low" level. The principle advantage of this method is that the "effect" determined for a calibration coefficient includes the influence of the K-1 other calibration coefficients being allowed to vary between their two levels simultaneously. The validity of the "one variable at a time" method is based upon the assumption that a factor's effect will not change when other factors vary. Another factorial design advantage is that any non-additive calibration coefficient effects, called interaction effects, are also calculated using this method.

A "one variable at a time" method requires an assumption that interaction between factors has no effect on results.

Sensitivity analysis is conducted on 24 of the 29 calibration coefficients. Some coefficients were not included in the analysis when doing so failed to make sense. For example, for reasons detailed elsewhere, recommendations are made to fix the value for two coefficients at a single level. Therefore, these were not included in the sensitivity analysis. The reason for excluding these coefficients is explained in a later section which details the results of this methodology for each calibration coefficient.

For K=24 coefficients, the 2^k design still requires a prohibitive number of model runs (in excess of 16 million) to include all coefficients in one experiment. Therefore the 24 coefficients were partitioned into five sets of eight coefficients for a total of five experiments. These five sets were selected on the basis of grouping combinations of inputs that appear to have the highest likelihood of interaction. Using this procedure five experiments, each containing 256 level combinations, reduced the total to a manageable 1280 runs of MOSCOW.

IV. FINDINGS

A. RECOMMENDED CALIBRATION COEFFICIENT VALUES

The primary benefit of this analysis is information pertaining to MOSCOW's use of each calibration coefficient. This information is detailed in Appendix B. The appendix should be used by model users already familiar with MOSCOW. The information presented in this appendix explains how each calibration coefficient is used by MOSCOW and provides a recommended value range when selecting calibration coefficient inputs. Users may find that their requirements lead to selecting calibration coefficient values outside the ranges listed in Appendix B. The recommended value ranges are based on the analysis performed and this author's opinion about which values return reasonably modelled sub-processes. For this reason, Appendix A provides a summarized list of calibration coefficient values with a "feasible" range (the valid input range for the coefficient within the MOSCOW program), a "likely range" (those coefficient values recommended in Appendix B), and a list of the coefficient values used in sensitivity analysis.

The calibration coefficient information in Appendix B applies to a modified version of RAND's MOSCOW-M1, called MOSCOW-NPS. MOSCOW-NPS contains code corrections made necessary when code verification analysis revealed problems

in MOSCOW-M1. The code corrections upon which MOSCOW-NPS is based are listed in Appendix C. This listing is by spreadsheet cell reference in LOTUS code format. Interested model users can identify and compare MOSCOW-M1 and MOSCOW-NPS differences using this information.

B. MOSCOW-M1 HAS A POORLY DESIGNED ENGAGEMENT TERMINATION PROCESS

Combat models require engagement termination rules to determine when battles end. MOSCOW-M1 employs an oversimplified battle termination rule which does not represent typical engagement logic and can yield improper engagement results. The weakness in the battle termination rule was discovered while researching MOSCOW's attrition module. The focus of this paper is to provide information about MOSCOW calibration coefficients, and part of the analysis methodology includes sensitivity analysis to determine the effect that different calibration coefficient values have on MOSCOW measures of effectiveness. This author believes that it is necessary to correct the battle termination problem rather than perform sensitivity analysis on model output which could be in error. The following paragraphs explain Lanchester combat model engagement termination rules and contrast battle termination in MOSCOW-NPS and MOSCOW-M1.

Engagements, whether scaled at small unit or theater levels, typically end when either side, given the ability to

disengage, receives an "intolerable" level of attrition. The "intolerable" level depends upon many factors, but can be established by two general considerations; the criticality of the immediate engagement's objective, and the ability to achieve the objective given the relative capacity of both forces at any point during the battle. Taylor presents a thorough analysis of battle termination alternatives, the most intuitive of which is based upon the Breakpoint Hypothesis [Ref. 5]. The corrections made to MOSCOW-M1 to develop MOSCOW-NPS follow this hypothesis.

> BREAKPOINT HYPOTHESIS: A unit will cease to be an effective fighting force in a fire fight when a given force level is reached. When this happens, the unit loses its ability to perform its mission and will "break off" the engagement. This force-level breakpoint depends upon the unit's type, size, and mission. [Ref. 5:p. 238]

Using the breakpoint hypothesis, both attack and defend forces have some breakpoint at which they will disengage, ending the battle.

The following variable definitions help explain the battle termination rules used in the MOSCOW model. This explanation is in the context of a Blue (X) force attacking a Red (Y) defender. A symmetrical relationship holds in the case where Red attacks Blue. Let:

1. X_o = Initial number of Blue (attack) units.
2. Y_o = Initial number of Red (defend) units.
3. X_{BP} = Number of Blue units surviving at the end of the battle.
4. Y_{BP} = Number of Blue and Red units surviving at the end of the battle.

5. T_{BP} = Time of the engagement;

6. a = Rate at which one Red unit kills Blue units.

7. b = Rate at which one Blue unit kills Red units.

8. DISENGAGE% = A value between zero and one which represents the ability of Blue to control the disengagement.

The Square law winning condition for the X force is:

$$X_o > Y_o\sqrt{\frac{a}{b}\left\{\frac{1-(Y_{BP}/Y_o)^2}{1-(X_{BP}/X_o)^2}\right\}} \tag{8}$$

Normally this condition is tested to determine which force "wins" the battle, and the time of battle is computed using the appropriate Lanchester time equation. If X fails the win condition test it reaches breakpoint before Y and the time of the battle is:

$$T_{XBP} = \frac{1}{\sqrt{ab}}\ln\left\{\frac{X_{BP}-\sqrt{X_{BP}^2-X_0^2+\frac{a}{b}Y_0^2}}{X_0-\sqrt{\frac{a}{b}}Y_0}\right\} \tag{9}$$

If X passes the win condition test the Y forces reaches breakpoint first and the time of the battle is:

$$T_{YBP} = \frac{1}{\sqrt{ab}}\ln\left\{\frac{Y_{BP}-\sqrt{Y_{BP}^2-Y_0^2+\frac{b}{a}X_0^2}}{Y_0-\sqrt{\frac{b}{a}}X_0}\right\} \tag{10}$$

An equivalent alternative is to compute both T_{XBP} and T_{YBP}, the minimum of which defines the battle outcome. For example, if T_{XBP} is the minimum time the X force "loses" the battle by

reaching its breakpoint level before the Y force. The larger of the two times has no meaning because the battle ends at the shorter time period.

The number of surviving units for each side is computed using the minimum breakpoint time in the following Lanchester force level as a function of time equations:

$$X(T_{BP}) = \frac{1}{2}\left\{\left(X_0 - \sqrt{\frac{a}{b}}\,Y_0\right)e^{\sqrt{ab}\,T_{BP}} + \left(X_0 + \sqrt{\frac{a}{b}}\,Y_0\right)e^{-\sqrt{ab}\,T_{BP}}\right\} \qquad (11)$$

$$Y(T_{BP}) = \frac{1}{2}\left\{\left(Y_0 - \sqrt{\frac{b}{a}}\,X_0\right)e^{\sqrt{ab}\,T_{BP}} + \left(Y_0 + \sqrt{\frac{b}{a}}\,X_0\right)e^{-\sqrt{ab}\,T_{BP}}\right\} \qquad (12)$$

where the "losing" force's survivors will correspond to its breakpoint level. Note that both surviving force levels are determined using the same breakpoint time since this is when the battle ends.

MOSCOW-NPS follows the breakpoint method for battle termination just described with two additional considerations. First, the breakpoint level for each force depends upon their ability to disengage from the enemy. The input DISENGAGE%, a value between zero and one, defines the Blue force's ability to control when disengagement occurs. This input modifies each side's desired breakpoint to establish the actual breakpoints used in the above Lanchester equations. Secondly, the engagement initial force strengths, X_0 and Y_0, are not explicitly input by the user. Both versions of MOSCOW follow

a convention that a single defending unit is attacked by the number of attacking units which meet the user input Attack/Defend Combat Power ratio. Using X as the attacking force, this Combat Power (CP) ratio is:

$$CP = \frac{X_o * b^{1/2}}{Y_o * a^{1/2}} \quad . \tag{13}$$

Using MOSCOW's convention, Y_o is always one, and X_o is determined by:

$$X_o = CP*(a/b)^{1/2} \ , \tag{14}$$

so the winning condition for the X force, Equation (8), becomes:

$$CP > \frac{(1-Y_{BP}{}^2)}{(1-(X_{BP}/X_o)^{1/2})} \quad . \tag{15}$$

Therefore, when using MOSCOW-NPS, engagement victory conditions are determined by relative force breakpoints and the Combat Power input.

RAND's version of the model, MOSCOW-M1, uses an abbreviated version of the battle termination rules just described for MOSCOW-NPS. There is only one time of battle equation, the time to the defender's breakpoint, used in MOSCOW-M1. The RAND version relies on a bold assumption that

the attacker will always continue to attack until a designated amount of attrition is achieved on the defender [Ref. 1:p. 155]. Battle termination is declared only when the defender is attrited to some designated fraction of its initial strength. Under this assumption the attacker continues to fight regardless of the attacker's own level of attrition. The attacking force, in MOSCOW-M1, will fight to self-annihilation if a set of inputs is such that the attacker lacks sufficient combat power to win the engagement. Using X as the attacking force, the time of battle equation in MOSCOW-M1 is always:

$$T_{YBP} = \frac{1}{\sqrt{ab}} \ln\left\{ \frac{Y_{BP} - \sqrt{\left| Y_{BP}^2 - Y_0^2 + \frac{b}{a} X_0^2 \right|}}{Y_0 - \sqrt{\frac{b}{a}}\, X_0} \right\} \qquad (16)$$

where T_{YBP} is the time to reach the Y force (defender) breakpoint. Note the important difference between the T_{YBP} for MOSCOW-NPS, Equation (12), and this T_{YBP}. The sum of the time equation terms $[Y_{BP}^2 - Y_o^2 + (b/a)(X_o^2)]$ for both equations will be negative when an X force attacker lacks the combat power to achieve the specified attrition level on the defender. These terms are within a radical operator in Equation (10), and when they sum to a negative value the complex root solution indicates that the attacking force size reaches zero before the defender is attrited to the specified level. The attacking force cannot win such a battle and the time of this type of engagement is defined as infinite.

In MOSCOW-M1 the absolute value of the sum of these terms is applied before applying the radical operator, which then yields a time solution which is "declared" to be the time the attacker takes to obtain the specified attrition on the defender. When the attacker lacks sufficient combat power, the use of the absolute value operator allows the time equation to report a finite time for attacker success, but the attacker actually cannot win the battle. Then, Equations (11 and 12) use the "declared" time of battle to find the number of forces surviving.

The following three figures graphically demonstrate the differences in battle termination results between the two models. They show the engagement results of an X force attacking a Y force at several different attacker/defender Combat Power ratios using the following example data:

1. Initial defender force strength, Yo = 1 unit, by MOSCOW convention.

2. Defender breakpoint, Y_{BP} = .60.

3. Initial attacker force strength, Xo = Determined by the Combat Power ratio shown on the horizontal axis.

4. Attacker breakpoint, X_{BP} = 0 , since MOSCOW-M1 always requires this condition. MOSCOW-NPS allows X to select other breakpoints.

5. Force lethality coefficients, a = b = 1; each force has same lethality, so combat power, in this example, is determined purely on the basis of initial force size.

The X force winning condition, from Equation (15) is then:

$$CP > [1 - (.60)^2]^{.5} = .80 \quad (17)$$

This means that the X force will "win," (the Y force reaches breakpoint first), when X attacks at Combat Power ratios greater than .80. When X attacks at Combat Power ratios of .80 or below, X reaches its breakpoint (in this case annihilation) before Y is reduced to sixty percent of its original strength.

Figure 5 compares the engagement times computed by each model for various Combat Power ratios. Note that when this ratio exceeds .80 the two models agree on engagement time. Both models operate in an identical fashion as long as the attacking force has enough combat power to "win" the battle according to the breakpoint hypothesis and compute engagement times based on the defender's breakpoint time.

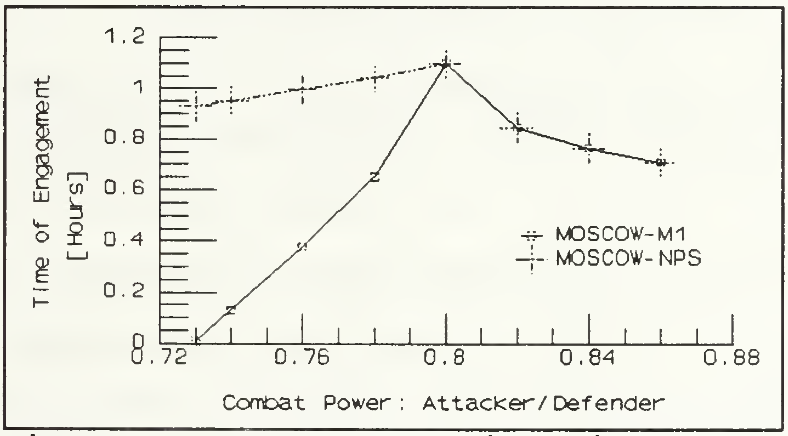

Figure 5. Engagement Time Differences Between MOSCOW Model Versions.

For Combat Power ratios below .80 (Equation 13) the two models provide different results. The engagement times computed by MOSCOW-NPS are according to the Lanchester square law and the

breakpoint hypothesis. For these smaller combat power ratios MOSCOW-NPS uses the time to the attacker's breakpoint equation, T_{XBP}. The MOSCOW-M1 times, however, are still based upon the time equation for the defender's breakpoint, T_{YBP}. The normal form of this equation does not have real root solutions since the terms under the radical operator sum to a negative value, but MOSCOW-M1's improper use of the absolute operator allows the equation to "claim" time solutions when, in fact, they are in error.

Figures 6 and 7 show the differences between model results for the levels of attack and defend force survivors. The equations computing these levels are identical for both models, but rely on the computed engagement times. The differences observed in survivor strength are caused by the engagement time differences explained earlier. Note that in both Figures 6 and 7, for Combat Power ratios greater than .80 (when the attacker "wins"), the models agree on survivor strength for both forces. For smaller Combat Power ratios the attacking force is annihilated before the defender reaches its breakpoint. MOSCOW-NPS reflects this known effect in Figure 6 since the attacker's survivor level is zero for all ratios below .80. In the same figure, MOSCOW-M1 shows that the further the attacker's Combat Power ratio falls below .80, the greater the number of surviving attack forces, which is an obvious error. The differences between surviving defender

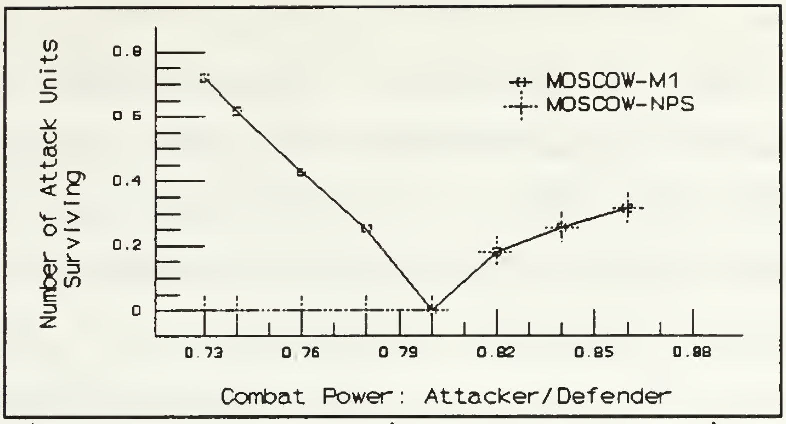

Figure 6. Attacking Force Survivor Differences Between MOSCOW Model Versions.

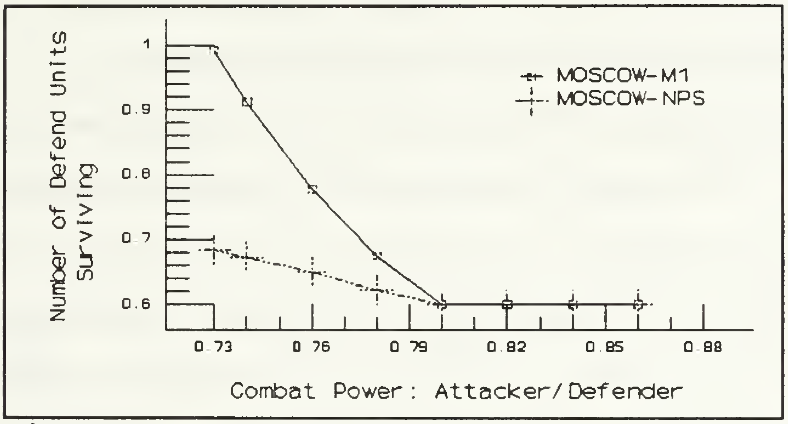

Figure 7. Defending Force Survivor Differences Between MOSCOW Model Versions.

levels are caused by the same problem. In Figure 7 MOSCOW-NPS shows that smaller Combat Power ratios result in a greater number of surviving defenders. This reflects the fact that a weaker attacking force is unable to attrite as many defenders before being annihilated. MOSCOW-M1 shows the same trend, but the solution it based on an incorrect engagement time.

When the attacker lacks sufficient combat power, the procedure used in MOSCOW-M1 underestimates the true Lanchester-based engagement time, attacker's attrition level, and defender's attrition level. The coding modifications to the Lanchester square law equations in MOSCOW-M1 attempt to compensate for a weak battle termination rule. The effect is that under some conditions the model may declare solutions in terms of time and attrition which are infeasible under Lanchester square law conditions.

C. LANCHESTER CALIBRATION COEFFICIENT L609

This calibration coefficient has no name, but is referred to in the calibration coefficient input section as the "Exponent of Numerical Strength in Lanchester Equations." This calibration coefficient is hereafter referred to as the "Lanchester coefficient." This calibration coefficient is present to allow the user to modify the standard Lanchester time of engagement equation. The general form of the equation for the X force in MOSCOW-M1 is:

$$T_{XBP} = \frac{1}{(ab)^{\frac{1}{n}}} \ln\left\{ \frac{X_{BP} - (X_{BP}^{n} - X_0^{n} + \frac{a}{b} Y_0^{n})^{\frac{1}{n}}}{X_0 - (\frac{a}{b})^{\frac{1}{n}} Y_0} \right\} \tag{18}$$

where n is the value selected for the Lanchester coefficient. This time equation corresponds to the Lanchester square law only if n equals two.

Romero's intent for changing the value for this calibration coefficient is to allow the user the flexibility of altering the time and subsequent attrition levels for engagements when the results fail to meet user requirements. The idea is that the time and subsequent attrition results can be "scaled" to the appropriate levels by changing this calibration coefficient value.

The problem with changing this coefficient is that the user is altering a time equation which is the unique solution to the set of differential equations and initial conditions defined by the Lanchester square law. The Lanchester square law begins by stating that attrition for opposing X and Y forces have the following differential form:

$$\frac{dx}{dt} = -aY \qquad \text{and} \qquad \frac{dy}{dt} = -bX \quad . \tag{19}$$

With initial conditions that at time zero, both forces begin with X_0 and Y_0 number of units, and the initial differential equations become:

$$\left.\frac{dx}{dt}\right|_{t=0} = -aY_0 \qquad \text{and} \qquad \left.\frac{dy}{dt}\right|_{t=0} = -bX_0 \tag{20}$$

where a and b are the constant rates at which X and Y firers kill enemy units.

These differential equations can be solved simultaneously as a second order homogeneous linear differential equation

initial value problem. The details of the solution are provided by Taylor [Ref. 6:pp. 222-231]. The solution for the X force as a function of time equation is:

$$X(T_{BP}) = \frac{1}{2}\left\{\left(X_0 - \sqrt{\frac{a}{b}}\,Y_0\right)e^{\sqrt{ab}\,T_{BP}} + \left(X_0 + \sqrt{\frac{a}{b}}\,Y_0\right)e^{-\sqrt{ab}\,T_{BP}}\right\} \quad (21)$$

Hartman [Ref. 5:pp. 12-13] also shows how this force level equation is solved for a corresponding equation which yields the time to reach a particular level of X force attrition. This equation is:

$$T_{XBP} = \frac{1}{\sqrt{ab}} \ln\left\{\frac{X_{BP} - \sqrt{X_{BP}^2 - X_0^2 + \frac{a}{b}Y_0^2}}{X_0 - \sqrt{\frac{a}{b}}\,Y_0}\right\} \quad (22)$$

which is identical to Equation (18) with n=2.

The point is that the form of this time equation is uniquely determined by the solution methods used starting with the initial square law differentials. By changing the Lanchester coefficient (n), the form of the attrition differentials which would yield the modified time equation is unknown. Without understanding the form of the original differentials implied by the modification, the user is plotting a course into uncharted territory where model results are unpredictable.

A feasible alternative may be the use of Helmbold equations, which are Lanchester type equations with an additional parameter that allows the user to modify them to

the desired form [Ref. 5:p. 18]. The underlying principles of these equations are well published, and therefore preferable to changing the Lanchester calibration coefficient in MOSCOW, which arbitrarily modifies the Lanchester square law solution.

The Lanchester coefficient in cell L609 should be set at a value of two so that model results rely on a well understood Lanchester square law foundation.

D. SENSITIVITY ANALYSIS RESULTS

Recommended calibration coefficient ranges are summarized in Appendix A and detailed in Appendix B. The objective of the sensitivity analysis is to determine the amount of change in MOSCOW MOE that one may expect when a calibration coefficient value is changed from the "low" end to the "high" end of the recommended range. The amount of MOE change provides information about how sensitive model results are to calibration coefficient changes within the recommended value range.

A 2^k factorial experimental design is used to determine the effect of calibration coefficient changes on MOSCOW MOE. Micro-computer capacity limitations preclude performing a single 2^{27} factorial experiment which includes all 27 of the tested coefficients. The best alternative was to partition the 27 coefficients into smaller subsets that appeared most likely to interact. Five sets of eight coefficients each were selected, for a total of five 2^8 factorial experiments. Each

experiment determined the effect of the eight coefficients on each of five MOSCOW MOE for an example scenario. The scenario inputs for the experiments are listed in Appendix D.

The MOE included in each of the experiments are identified below.

1. Initial Number of Maneuver (MVR) Units Required. This MOE represents the number of Blue Maneuver units required to achieve campaign success. It does not include replacement personnel or vehicles required to maintain these units at full strength during the campaign.

2. Replacement Personnel. This MOE is the number of personnel replacements to maintain maneuver units at full strength during the campaign. This value reflects casualties incurred during the campaign by BLUE maneuver units.

3. Replacement Vehicles Needed. This measure is the number of replacement vehicles that are required to maintain Blue units at full strength during the campaign. The MOE represents vehicle losses by Blue Units.

4. Ammunition Required. Ammunition required is the tonnage of ammunition fired by Blue units during the campaign.

5. Campaign Length. This MOE is the time, in days, that Blue forces delay Red forces from reaching a specified penetration limit during the campaign. Campaign success is measured in terms of achieving a given attrition level on the Red force by the time this penetration is reached. Campaign success is always achieved by the Blue force, but the amount of delay imposed varies by the set of inputs which describe the "concept" of warfare used in the scenario. Blue units desire longer delay times.

In a factorial experiment, each coefficient (called a factor) has two values, called levels, "high" and "low." A test is performed (in this case a MOSCOW model run) for all possible level combinations, and MOE results are recorded. Since MOSCOW is a deterministic model, no test variation

considerations are required, therefore, repetition to estimate effect variation is unnecessary. The "effect" of a factor (coefficient) measured by the experiment, is the difference between the average MOE value for all model runs when the factor is at a high level and the average MOE value for all model runs when the same factor is at a low level.[2] The effect of a factor represents the average range of change observed for an MOE due to changing the level of the factor. This range of change just described is specified in MOE units of measure. For example, if an effect of a factor on ammunition is 350, it means that varying the factor causes the ammunition MOE to change by an average of 350 tons. This method requires the user to "scale" the listed effects to the actual MOE value. For example, a 350 ton range change for ammunition is a large effect if the average ammunition value is 700, but small if the average MOE value is 35000 tons.

Rather than report effects in terms of MOE units, the effects described above can be divided by the average MOE values for all model runs. This technique does not alter

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[2]This is the same type of sensitivity analysis performed by Hoffman [Ref. 4:pp. 18-22], except that this analysis applies exclusively to calibration coefficients. Hoffman's work dealt with force and scenario inputs. Effect significance was computed using a modified version of the Input Sensitivity program written by Hoffman [Ref. 4;pp. 95-98]. The modification uses the average MOE value for all model runs, (rather than the average MOE value for model runs when the input is at a low level) for determining the significance level of an input's effect. This code modification consists of replacing the code "MOE[;1]" with "(+/MOE)÷(256)" in lines 103 and 115 of Hoffman's program.

results, but allows effects to be reported on a common, dimensionless scale. The effect of a factor in these terms becomes the percentage change observed for an MOE due to changing the level of the factor. The advantage of this method is that readers do not have to be familiar with the relative order of magnitude between the effect and the average MOE value. The effects listed below are in percentage terms, which implicitly specify relative magnitudes. For example, the effect of a factor listed as -.09 on ammunition means that changing the factor from a high to low level causes the average MOE value to decrease by nine percent. Note that effects have signed values. A positive effect means that changing the factor from a high to a low level increases the average MOE value by the listed percentage.

The effects listed in Tables 1 through 5 are those which cause at least a one percent change in MOE results. The actual level of significance (the percentage change a factor has on an MOE) of each factor is listed for each tested MOE. Presenting the effects in this manner allows readers to make their own judgments about the significance of each factor's effect. Factors which cause less than a one percent MOE value change are not listed because they are obviously not significant for the tested scenario.

The following eleven calibration coefficients failed to produce at least a one percent change for any of the five tested MOE:

TABLE 1

EXPERIMENT ONE
MEASURE OF EFFECTIVENESS

FACTOR (CAL. COEFFICIENT)	MVR UNITS REQUIRED	PERSONNEL REPLACEMENTS	VEHICLE REPLACEMENTS	AMMUNITION REQUIRED	CAMPAIGN LENGTH
L665		–.0106	–.0104		
L667	.0787	.0508	.0472	.0189	
L670	.1079	.0625	.0643		

LEGEND:
L665 PWRCOEFAIDISR
L667 FRNTAGELETHCOEF
L670 %REDBREAK/KM

TABLE 2

EXPERIMENT TWO
MEASURE OF EFFECTIVENESS

FACTOR (CAL. COEFFICIENT)	MVR UNITS REQUIRED	PERSONNEL REPLACEMENTS	VEHICLE REPLACEMENTS	AMMUNITION REQUIRED	CAMPAIGN LENGTH
L621	–.1717	–.1194	–.1249	–.0549	–.0170
L654	.0100				
L678	.0346	.0986	.0898	.0135	.0125
L686		.0211	.0186	.0180	
L708	–.0963	.–.0643	–.0678	–.0294	
L711	.0554	.0279	.0266	–.0286	–.0393
L621*L708	.0963	.0643	.0678	.0294	
L621*L711	–.0113				

LEGEND
L621 BASELINE%REST
L654 PWRCOEFIERR–ATK
L678 ATKTERMULTCOEF
L686 DISMTDLETCOEF
L708 LOWRESTCOEF
L711 (UNNAMED)

TABLE 3

EXPERIMENT THREE

FACTOR (CAL. COEFFICIENT)	MVR UNITS REQUIRED	PERSONNEL REPLACEMENTS	VEHICLE REPLACEMENTS	AMMUNITION REQUIRED	CAMPAIGN LENGTH
	MEASURE OF EFFECTIVENESS				
L619	−.3749	−.0191	−.0383	−.0375	.0332
L690	−.0300				.0103
L692	−.0362			.0135	.0111
L696	.0503			.0180	
L701	.0171			.0146	.0202
L619*L692	.0192				

LEGEND:
L619 HRS/DEFPREP%　L696 HQBURDCOEFC3ER
L690 IERRCOEFSURVTM　L701 REDSURVDISCOEF
L692 HQLOADDELCOEF

TABLE 4

EXPERIMENT FOUR

FACTOR (CAL. COEFFICIENT)	MVR UNITS REQUIRED	PERSONNEL REPLACEMENTS	VEHICLE REPLACEMENTS	AMMUNITION REQUIRED	CAMPAIGN LENGTH
	MEASURE OF EFFECTIVENESS				
L619	−.3450	−.0196	−.0375	.0327	.0299
L621	−.1674	−.1181	−.1235	−.0535	−.0160
L639	−.0154				
L708	−.0946	−.0628	−.0664	−.0283	
L621*L708	.0947	.0628	.0663	.0283	

LEGEND:
L619 HRS/DEFPREP%　L639 REDVEH/KM2SEC
L621 BASELINE%REST　L708 LOWRESTCOEF

TABLE 5

EXPERIMENT FIVE

FACTOR (CAL. COEFFICIENT)	MEASURE OF EFFECTIVENESS				
	MVR UNITS REQUIRED	PERSONNEL REPLACEMENTS	VEHICLE REPLACEMENTS	AMMUNITION REQUIRED	CAMPAIGN LENGTH
L667	.0805	−.0308	.0147		.0299
L670	.0770	.0904			−.0160
L678	.0694	.0648			
L686	.0208	.0613			
L667*L670	.0947	−.0475			
L667*L678		−.0756			
L670*L678		.0465			
L667*L686		−.0616			
L670*L686		.0550			
L678*L686		.0496			
L667*L670*L678		−.0475			
L667*L670*L686		−.0564			
L667*L678*L686		−.0634			
L670*L678*L686		.0547			
L667*L670*L678*L686		−.0565			

LEGEND
L667 FRNTAGELETHCOEF
L670 %REDBREAK/KM
L678 ATKTERMULTCOEF
L686 DISMTDLETHCOEF

1. L628, REDLEADVEH-ATK
2. L631, BLUELEADVEH-ATK
3. L636, BLUVEHKM/SEC
4. L651, PWRCOEFTGTAVAIL
5. L657, PWRCOEFCASKIL
6. L660, PWRCOEFAIKILS
7. L663, PWRCOEFAIDEL
8. L675, MILUSBLCOEF
9. L683, DISMTDVULNCOEF
10. L694, HQBURDDELCOEF
11. L703, RECONSTMCOEF

Varying these coefficient values within the tested range fails to produce any significant change in any of the five test MOE for the example scenario. These results imply that little attention need be paid when selecting their input values, since they do not significantly affect model results. The sensitivity experimentation results do not provide final answers concerning the utility of these coefficients. The factorial experiments only provide initial indications about the effect of these coefficients.

The possibility exists that the tested scenario failed to create a situation that allowed some coefficients to have significant effect. For example, RED(or BLUE)LEADVEH-ATK, (L626 and L631), only have influence in the model if a narrow defense frontage reduces the attacker's desired combat power.

If the defense frontage is not too small, these coefficients have no effect in that particular scenario.

A second possibility is that the model adequately represents combat processes which have little or no effect in an actual campaign. For example, it may be that aerial interdiction delay missions have little effect, in general, in the outcome of a campaign. In this case, PWRCOEFAIDEL (L663), which had no significant effect in the experiments, may be properly represented by the model.

Another possibility is that the model fails to adequately represent some actual combat processes. For example, one would expect that air support, in general, has a significant impact on campaign outcome. The experiments show that only one of the four coefficients which modify air support has a significant effect on MOSCOW MOE. If the input values for these coefficients properly represent air support capabilities, then the model may inadequately represent air support effects on campaign outcome.

Finding particular reasons why each coefficient has the effect determined by this set of experiments is a considerable task beyond the intended purpose of this research. Examining causes for the listed effects should be the focus of additional work on the model. The effects should be considered as an indicator, not the final explanation, of the actual result one can expect when changing calibration coefficient values.

V. RECOMMENDATIONS

Rand Corporation should revise MOSCOW documentation. Work by Hoffman, [Refs. 3 and 4] and this analysis, provide additional information about MOSCOW. The need for this information is primarily based upon the lack of detailed user's guidance in Rand documentation for selecting MOSCOW inputs. Hoffman's work [Ref. 3] should be used to add a section to Rand's User's Guide, [Ref. 2] explaining one methodology for aggregating MOSCOW inputs for opposing forces. Appendix B of this document should be used to add a section to Rand's User's Guide for selecting MOSCOW calibration coefficients. Supplementing existing documentation with this information would assist MOSCOW user's to determine sets of inputs which reflect their desired "concept" of operational warfare.

Rand Corporation should consider revising portions of MOSCOW code. The findings in Chapter IV explain the weakness in MOSCOW-M1's battle termination rule. MOSCOW-M1 coding should be revised to support the breakpoint hypothesis developed in Chapter IV. Revision to include the breakpoint hypothesis is easy to perform, does not complicate the model, but yields greater flexibility and more reliable model results. The required code changes, already included in MOSCOW-NPS, are listed in Appendix C.

Additional code corrections are required to correct problems that exist in the application of calibration coefficients to modelled sub-processes. Code corrections made for MOSCOW-NPS to eliminate problems found in MOSCOW-M1 are also listed in Appendix C. Rand should compare these code corrections to the MOSCOW-M1 version and make appropriate revisions.

Additional sensitivity analysis should be performed on MOSCOW. A number of calibration coefficients appear to have little effect on MOSCOW results. These calibration coefficients identified in Chapter IV should be analyzed in more detail to determine if they consistently fail to affect model results over a wide range of scenario types. If these coefficients provide effects under special conditions, the information should be included in model documentation. If the coefficients consistently fail to affect MOSCOW results, the code should be revised or the coefficients removed from the model. The purpose of additional sensitivity analysis, a substantial task, should be to explain why calibration coefficients show particular effects on various MOSCOW MOE.

Interested model users should use MOSCOW-NPS until a suitable revision is made by Rand Corporation. MOSCOW-NPS contains code revisions which make it an improved version of MOSCOW-M1. MOSCOW-NPS provides Lanchester square law results based upon the breakpoint hypothesis explained in Chapter IV. Appendix B also provides calibration coefficient selection

guidance that does not apply to some portions of the Rand version of MOSCOW. Other inputs for the two versions of the model are identical. MOSCOW-M1 should only be used after suitable revision is made which corrects model coding, and improved model documentation is published. Inquiries about MOSCOW-NPS should be referred to Dr. S. Parry at the address listed in the distribution section of this work. Moscow-M1's author, P. Romero, believes that future model documentation should include information provided by this thesis and work by Hoffman. The incorporation of code changes listed in Appendix C will depend upon RAND Corporation's evaluation of the incensed utility that may be realized from their use.

APPENDIX A

ABBREVIATED CALIBRATION COEFFICIENT INFORMATION

The tables below summarize the value ranges which apply to each calibration coefficient. The coefficient name and spreadsheet cell reference are listed to facilitate cross reference with the model. The feasible range column identifies calibration coefficient values which MOSCOW will accept and still run. The likely range column represents the calibration coefficient range recommended for use as a result of this analysis. The sub-process affected by each coefficient appears reasonable when selecting values from the likely range. The tested levels column reports the levels at which each coefficient was varied during sensitivity analysis.

TABLE 6.
MOSCOW CALIBRATION COEFFICIENT RANGES-MANDATORY LIST

COEFFICIENT	CELL	FEASABLE RANGE	LIKELY RANGE	TESTED LEVELS
LANCH EXP	L609	Fix at 2.0	2.0	2.0
TEMPO	L613	Fix at 1.0	1.0	1.0
HRS/DEFPREP%	L619	(0, 8)	(0, 1)	(.25, .75)
BASELINE%REST	L621	(0, 1)	(.2, .33)	(.2, .33)
MAXFIRESPT	L623	(0, INF)	(.25, 1.75)	(.5, 1.5)
REDLEADVEH-ATK	L628	(0, 1)	(.05, .95)	(.10, .50)
BLULEADVEH-ATK	L631	(0, 1)	(.05, .95)	(.10, .50)
BLUVEHKM2SEC	L636	(0, INF)	(0, SMALL)	(.003, .01)
REDVEH/KM2SEC	L639	(0, INF)	(0, SMALL)	(.003, .01)

TABLE 7.
MOSCOW CALIBRATION COEFFICIENT RANGES-OPTIONAL LIST

COEFFICIENT	CELL	FEASABLE RANGE	LIKELY RANGE	TESTED LEVELS
PWRCOEFTGTAVAIL	L651	(0, INF)	(3, 15)	(5, 12)
PWRCOEFIERR-ATK	L654	(0, INF)	(0, 2)	(.5, 1.5)
PWRCOEFIERR-DEF	L655	(0, INF)	(0, 2)	(.5, 1.5)
PWRCOEFCASKIL	L657	(0, INF)	(0, 1)	(.25, .75)
PWRCOEFAIKILS	L660	(0, INF)	(0, 1)	(.25, .75)
PWRCOEFAIDEL	L663	(0, INF)	(0, 1)	(.25, .75)
PWRCOEFAIDISR	L665	(0, INF)	(0, 1)	(.25, .75)
FRNTAGELETHCOEF	L667	(0, INF)	(1, T48)	(1, T48)
%REDBREAK/KM	L670	(0, INF)	(0, .01)	(.002, .01)
MILUSBLCOEF	L675	(0, INF)	(0, 2)	(.5, 1.5)
ATKTERMULTCOEF	L678	(1, INF)	(0, 5)	(1, 5)
DISMTDVULNCOEF	L683	(0, INF)	(.5, 1.5)	(.5, 1.5)
DISMTDLETHCOEF	L685	(0, INF)	(0, 1)	(.25, .75)
IERRCOEFSURVTM	L690	(0, INF)	(0, 2)	(.5, 1.5)
HQLOADDELCOEF	L692	(0, INF)	(0, 2)	(.5, 1.5)
HQBURDDELCOEF	L694	(0, INF)	(0, 1)	(.25, .75)
HQBURDCOEFC3ER	L696	(0, INF)	(0, 2)	(.5, 1.5)
REDSURVDISCOEF	L701	(1, INF)	(3, 15)	(5, 12)
RECONSTMCOEF	L703	(0, INF)	(0, .1)	(.025, .075)
LOWRESTCOEF	L708	(0, INF)	(0, 4)	(.5, 1.5)
(Not Named)	L711	(0, INF)	(0, 2)	(.5, 1.5)

The following abbreviated definitions provide quick reference about the use of each calibration coefficient. A detailed description for each coefficient is given in Appendix B.

L609, LANCHESTER EXPONENT
Allows model users to alter the basic form of the Lanchester square law time of battle equation.

L613, TEMPO
Allows model users to modify the time of battle reported to the model output section. The original engagement time, computed by the Lanchester square law, is not altered by this coefficient.

L619, HRS/DEFPREP%
The rate at which forces spend time to achieve one percent increments of additional terrain protection by preparing defense.

L621, BASELINE%REST
The threshold level of rest (in fractions of a day) below which soldiers begin to lose some degree of effectiveness.

L623, MAXFIRESPT
An upper bound (in multiples of maneuver unit lethality) on the lethality that Artillery and close air support may have in the model.

L628, REDLEADVEH-ATK
The fraction of the Red force's vehicles that lead Red attacks.

L631, BLULEADVEH-ATK
The fraction of the Blue force's vehicle that lead Blue attacks.

L636, BLUVEHKM2/SEC
The number of Blue personnel (not vehicles as indicated by the name) per square kilometer which are assigned security force missions. These forces are not involved in engagements.

L639, REDVEH/KM2SEC
The number of Red personnel (not vehicles as indicated by the name) per square kilometer which are assigned security force missions. These forces are not involved in engagements.

L651, PWRCOEFTGTAVAIL
Affects target availability of a force, to the enemy, based on the effects of relative force ratio.

L654, PWRCOEFIERR-ATK
Affects the availability of attacking force targets to the defender, based upon intelligence error and the "risk" involved in the aggressive nature of the attack.

L655, PWRCOEFIERR-DEF
Affects the availability of defending force targets to the attacker based upon intelligence error and force ratio effects.

L657, PWRCOEFCASKIL
Affects the lethality of Artillery and close air support weapons based upon relative target density (force ratio).

L660, PWRCOEFAIKILS
Affects the lethality of aerial interdiction sorties based upon force ratio.

L663, PWRCOEFAIDEL
Affects the amount of enemy movement delay caused by aerial interdiction delay sorties based upon force ratio.

L665, PWRCOEFAIDISR
Affects the amount by which aerial interdiction sorties increase enemy C3 error based upon force ratio.

L667, FRNTAGELETHCOEF
Reduces the amount of terrain protection defenders receive when they attempt to defend a wider frontage than allowed by their normal capability.

L670, %REDBREAK/KM
The fraction of Red force vehicles that are lost due to non-combat related "breakdowns".

L675, MILUSBLCOEF
Affects the fraction of the campaign zone considered militarily usable. Only militarily usable terrain is occupied by opposing forces.

L678, ATKTERMULTCOEF
Reduces the amount of terrain protection an attacker receives by virtue of being the aggressor.

L683, DISMTDVULNCOEF
Determines the vulnerability of dismounted Infantry.

L685, DISMTDLETHCOEF
Determines the degree by which dismounted Infantry modifies a force's lethality.

L690, IERRCOEFSURVTM
Determines the Time of the Survey and Reconnaissance Activity for a force based on its level of intelligence error.

L692, HQLOADDELCOEF
Affects the amount of "wasted" time caused by the "load" (in number of subordinate units commanded) on a force's headquarters elements.

L694, HQBURDDELCOEF
Affects the amount of "wasted" time caused by headquarters elements when they command more subordinate units than their normal design capacity.

L696, HQBURDCOEFC3ER
Determines the amount by which a force's C3 error increases due to headquarters burden (see L694).

L701, REDSURVDISCOEF
Affects the ability of Red force survivors to delay Blue force disengagements.

L703, RECONSTMCOEF
Affects the amount of time Blue forces spend re-organizing and assessing casualties between engagements.

L708, LOWRESTCOEF
Affects the degree by which lack of rest degrades Blue force effectiveness (movement and lethality).

L711, (Not Named)
Affects the ability of Red forces to overcome the effects of C3 error by outmaneuvering Blue forces.

APPENDIX B

DETAILED CALIBRATION COEFFICIENT INFORMATION

This appendix provides detailed descriptions of MOSCOW calibration coefficients. The descriptions are intended for MOSCOW users who are already familiar with RAND's documentation on the model [Ref. 1 and 2]. Guidance for other inputs may be found in Hoffman's work [Ref. 3 and 4]. Furthermore, this appendix provides MOSCOW users with information to intelligently select input values for these coefficients. Each description results from analysis of the MOSCOW model using the methodology outlined in Chapter III. Recommended ranges for each coefficient contain values which, in the author's best judgement, make each modelled combat sub-process function within reasonable limits.

RAND's current version of the model, by Romero, is called MOSCOW-M1. Many model code corrections were made to this version. These corrections resulted from the verification of the model's code to ensure that modelled sub-processes correspond with documented intent, had symmetrical effects on opposing Red and Blue forces, or met with intuitive appeal. A revised version of MOSCOW, called MOSCOW-NPS, contains all of the code corrections listed in Appendix C. The descriptions presented here apply to MOSCOW-NPS. MOSCOW-M1

currently retains calibration coefficient problems discovered as a by-product of this analysis.

Actual calibration coefficient names are used to facilitate cross reference with MOSCOW spreadsheet code and existing documentation. The headings for each calibration coefficient include its name and the corresponding spreadsheet input cell (e.g., LOWRESTCOEF, cell L706.). This method is used because the calibration input section uses only cell references. The spreadsheet code predominantly refers to coefficient names. Figures in this appendix contain coefficient names and corresponding spreadsheet cell references. MOSCOW users should find this technique valuable when using the model.

LANCHESTER Coefficient, cell L609.

This coefficient is used to modify the form of the basic Lanchester square law equations used in MOSCOW's attrition module. Lanchester square law equations use a value of two for this coefficient. Selecting values other than two may lead to unpredictable results since the form of the underlying attrition differentials are unknown for these values. (See Chapter IV, part B, for the details which argue for fixing this coefficient at a value of two.)

TEMPO, cell L611.

MOSCOW computes the time friendly units spend in various activities during the campaign. The model user may analyze

the time distribution among these activities to determine differences between warfighting concepts. Three activities, ATK1, ATK2, and DEFEND represent the time spent actually engaging the enemy during the campaign. Other activities represent time units spend in preparation and support events required to sustain the capability to engage the enemy during the campaign. Time spent in ATK1, ATK2, and DEFEND activities is based upon Lanchester square law results computed in the attrition module. The length of each engagement depends upon relative combat power and attrition preferences for opposing forces.

The TEMPO coefficient is a constant, set by the user, to adjust the Lanchester based engagement time as computed in the attrition module, before it is reported to the Time of Activities section of the model. TEMPO does not affect how MOSCOW calculates attrition. The coefficient only adjusts the engagement time listed in model output.

This coefficient should be left set to a value of one. Model users should understand, and take into consideration, the implications of using Lanchester based attrition when using the model. The time of the battle and relative attrition levels for each force depend upon this attrition method. When the user finds that length of engagements and corresponding attrition levels appear inappropriate, then the cause for the discrepancy should be researched in terms of the inputs which lead to the calculation of Lanchester lethality

parameters. These lethality parameters set the pace of the battle by defining the "intensity" or lethality of engagements [Ref. 5:p. 5.7]. Engagement times should be modified by defining inputs which affect these lethality parameters to suit user requirements within the square law formulation. Changing the TEMPO coefficient provides a false impression that the level of engagement attrition is achieved in the modified time under a square law formulation, when in fact, this is not the case.

<u>HRS/DEFPREP%, cell L619.</u>

MOSCOW allows defending units to increase their defense strength by spending time preparing defense. A set of terrain inputs describes the relative fraction of different terrain types that exist within the campaign zone. Each terrain type has an associated "defense strength" value. The larger this defense strength value, the more protection a defender receives during engagements due to terrain advantage. The defender is always provided a level of protection corresponding to the average defense strength of all terrain in the zone. The defender may choose to spend time "preparing defense" to increase this average level of terrain protection. The amount of additional protection available is equal to the difference between the defense strengths of the "average" and "most defensible" terrain in the zone. For example, let

1. Defense strength of most defensible terrain type = 2.00.

2. Defense strength of average terrain in zone = 1.10. The amount of additional protection, or "defense strength" available to the defender by preparing defense is (2.00 - 1.10) = .90.

The input "Defense Prep%" is the fraction of additional protection available that the defender chooses to achieve by spending additional time preparing defense positions. A value of zero for "Defense Prep%" implies that the defender receives only the average terrain defense strength. A value of one implies that the defender receives all addition protection, which equals that corresponding to the most defensible terrain in the zone. It costs the defender time to increase his level of protection. The defender must weigh the fraction of additional protection desired against the time "penalty" spent in a "prepare defense" activity. Additional protection is an advantage during engagements, but time spent preparing defense means a unit is unavailable for combat for a longer period between engagements. The calibration coefficient HRS/DEFPREP% is the number of hours required to increase the defender's strength by one percent of the additional terrain protection available. The coefficient is a rate, selected by model users to represent the time penalty a defender pays to improve defense positions.

For example, given the strength information above, let:

1. Defense Prep% = .50
2. HRS/DEFPREP% = .45

The defense strength achieved is then:

$$1.10 + .5(2.00 - 1.10) = 1.55$$

at a "Prepare Defense" activity cost of:

$$.45 \times 100(.5) = 22.5 \text{ [HRS]} = .9375 \text{ [DAYS]}.$$

Figure 8 shows how "Prepare Defense" activity time is affected by HRS/DEFPREP% values between zero and one. As HRS/DEFPREP% increases the activity time is more sensitive to changes in the fraction of additional protection (Defense Prep%) selected by the defender. The recommended range for this calibration coefficient is between zero and one. A value of zero implies

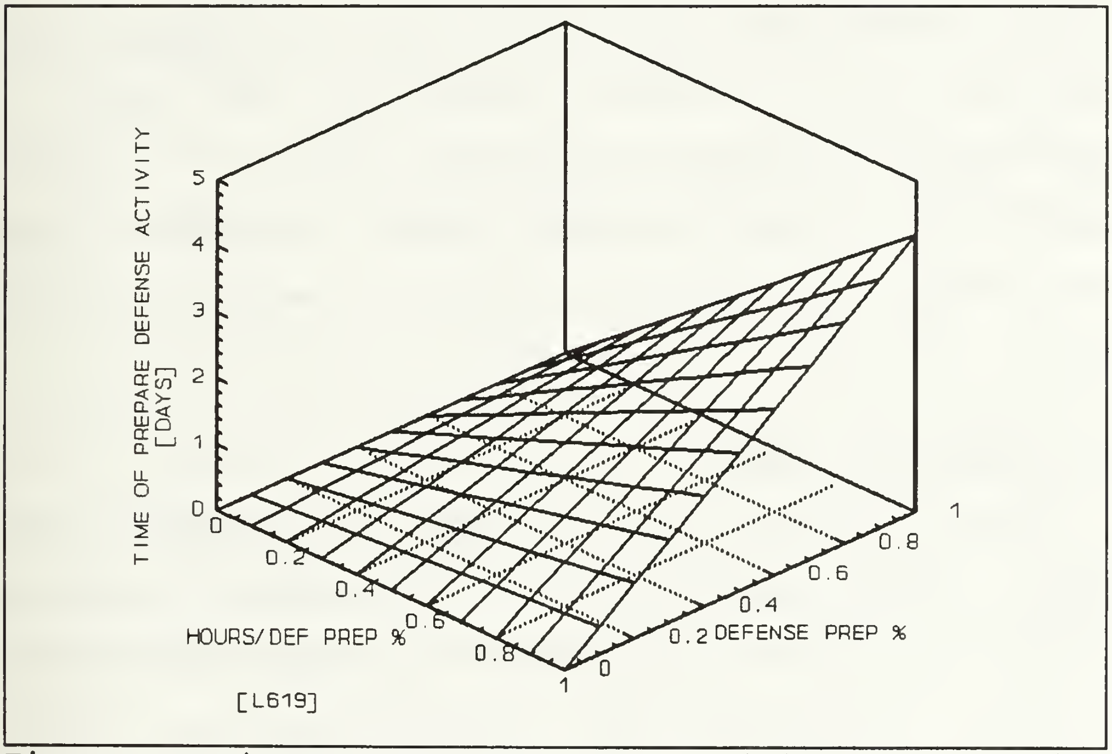

Figure 8. Time of Prepare Defense Activity as a Function of HOURS/DEF PREP% and DEFENSE PREP%.

that the defender must spend one day preparing defense to gain each additional one percent increase in terrain protection. Setting this value to one implies that a defender can achieve increased protection with no preparation time.

BASELINE%REST, cell L621.

BASELINE%REST is simply the fraction of a day units must sleep, or rest, to maintain their standard effectiveness level. This coefficient is set to a reasonable value for the amount of rest soldiers require to be fully effective. The recommended range is between .2 and .33 days (roughly 5-8 hours).[3]

This calibration coefficient is used as a threshold level for rest and is explained further in the section on "LOWRESTCOEF." The actual rest a unit receives is a separate input which, when used with BASELINE%REST, determines whether effectiveness (lethality and mobility) is degraded by lack of rest.

MAXFIRESPT, cell L623.

MOSCOW combines the kill rates from maneuver units, general support indirect fire, and air support for use as lethality parameters in its Lanchester based attrition module

[3]The effect of sleep varies between individuals, however, there is reason to believe that approximately eight hours of sleep per day provides adequate rest for humans engaged in continuous operations. This implies that values close to .33 should be used. See Reference 7 for one example of research into this topic.

calculations. General support indirect fires and air support kill rates are combined first into a single "support" kill rate. MAXFIRESPT is any fraction or multiple of the maneuver kill rate. Before being added to the maneuver kill rate, the "support" kill rate is compared to the kill rate defined by MAXFIRESPT. The purpose of MAXFIRESPT is to allow the user to establish an upper bound for the "support" kill rate as a function of the maneuver kill rate. The lesser of the "support" or upper bound kill rate defined by MAXFIRESPT is the actual value added to the maneuver kill rate.

The value selected for MAXFIRESPT depends upon the scenario modelled. A value less than one implies that support air and artillery cannot have a higher total lethality than maneuver units. A value greater than one implies that air and artillery can have a higher combined lethality than maneuver units.

A value between .25 and 1.75 for MAXFIRESPT appears reasonable for most scenarios. This range is recommended because support air and artillery capability, relative to maneuver, based on current U.S. Army unit task organization falls well within these limits. Model users should carefully consider this upper bound value based on the relative mix of maneuver and support assets. When setting this value the model user is actually specifying an upper bound on the effects of indirect fire and air support, reflecting some inherent expectation of the model user. If the actual

"support" kill rate determined by MOSCOW exceeds this bound then it also exceeds the user's expectation. In such a case it may be wise to examine the inputs which MOSCOW uses when computing "support" lethality to determine the cause rather than blindly accepting model results. If "support" lethality appears reasonable perhaps maneuver lethality is lower than expected.

<u>REDLEADVEH-ATK, cell L628, and BLUELEADVEH-ATK, cell L631.</u>

These calibration coefficients are defined as the percentage of an attacking force's vehicles that actually lead the attack. Each coefficient has the same effect, but allow different values to be selected for opposing forces. Their effect is to determine the maximum number of vehicles an attacker may use against a defender.

The attacking force will attempt to gather the number of vehicles required to attack with the desired ATTACKER/DEFENDER combat power ratio. These calibration coefficients are used in a part of MOSCOW that captures the effect that "shoulder" space has on the attackers ability to mass the desired number of vehicles in the attack. This "shoulder" space is the frontage within which vehicles must fit when conducting an attack.

Figure 9 demonstrates how frontage limits the number of vehicles that can be physically placed "on-line" in the attack. The frontage width is determined by a combination of

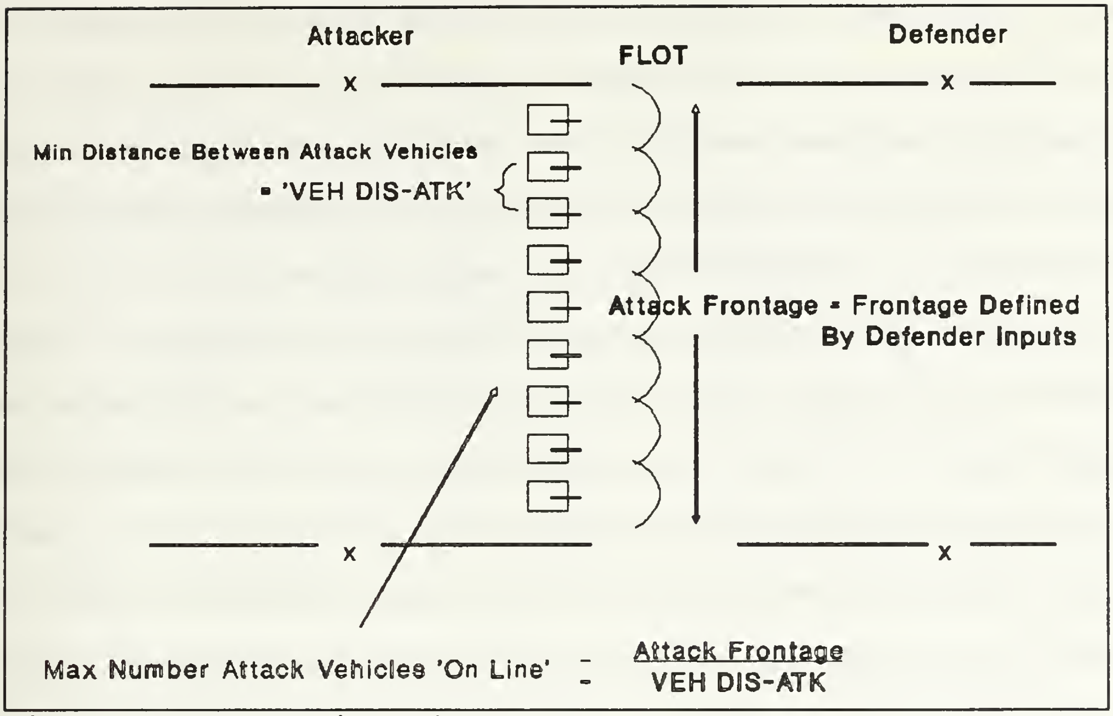

Figure 9. Relationship Between VEH DIS-ATK and Attack Frontage for Computing the Maximum Number of Vehicles Which Can Be Placed 'On Line' in an Attack.

inputs defined by the defender. Attack frontage equals this defender frontage. The attacker selects a minimum lateral distance between attack vehicles corresponding to the desired "warfighting style." This distance is an input called "DISVEH-ATK." Attack frontage divided by "DISVEH-ATK" defines the maximum number of vehicles that can be placed "on-line" in an attack. The maximum number of "on-line" vehicles represents some portion of the total attacking force.

The calibration coefficients (RED or BLUE)LEADVEH-ATK are inputs which specify the fraction of the attacker's total force which lead their attack "on-line." The maximum number

of vehicles that may be placed "on-line" and these calibration coefficients define the upper limit for the total number of attacking vehicles used in an engagement. The upper limit is simply the maximum number of "on-line" vehicles divided by the calibration coefficient (RED or BLUE)LEADVEH-ATK.

Figure 10 shows the relationship described above. These calibration coefficients may be interpreted as defining the "depth" of the attack. A calibration coefficient value of one means that the entire attacking force is placed "on-line." This means that the upper bound on total vehicles equals the number that will fit "on-line" in the attack frontage width.

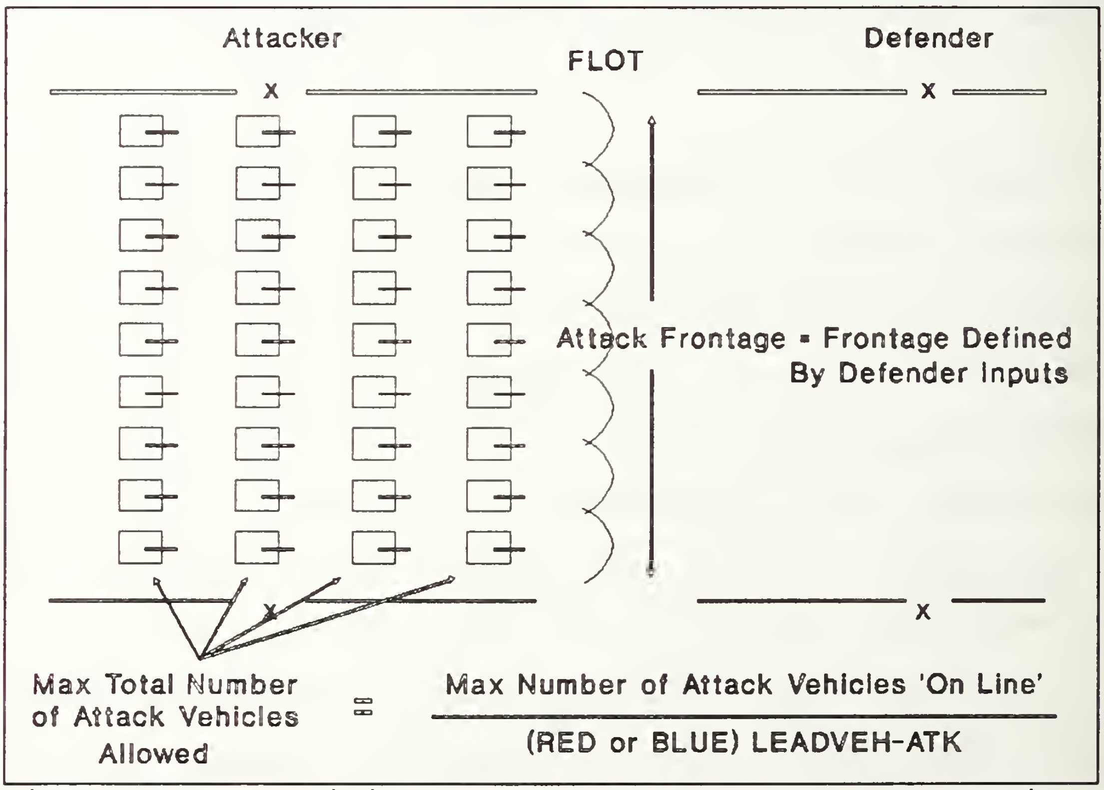

Figure 10. Coefficient RED(or BLUE)LEADVEH-ATK Determines Maximum Attacking Vehicles Allowed During Engagements.

A calibration coefficient value of .5 means that the upper limit on total attack vehicles equals twice that which fit "on-line" in the attack frontage width. A smaller calibration coefficient value implies more "depth", increasing the maximum allowable total number of attacking vehicles.

It is important to understand that this process determines the attacker's upper bound for vehicles. The actual number of vehicles used in an attack is the minimum of this upper bound or the number of vehicles required to mass the attacker's desired attack/defender combat power ratio. If the upper bound is the minimum, then attacks are conducted at some combat power ratio smaller than the attacker's preference. The value for these calibration coefficients must always be greater than zero and less than or equal to one.

BLUVEH/KM2SEC, cell L636, and REDVEH/KM2SEC, cell L639.

These calibration coefficients are used to determine the number of security forces required for each opponent. The security forces are not used during engagements but represent the units that must be "reserved" to provide security while the rest of the force conducts assigned missions. The amount of security required depends upon force needs corresponding to the "warfighting style" and "risk" accepted by decision makers.

In MOSCOW, campaign operations are conducted in an area represented by a rectangular zone similar to that shown in Figure 11. The Red force attacks from the zone forward

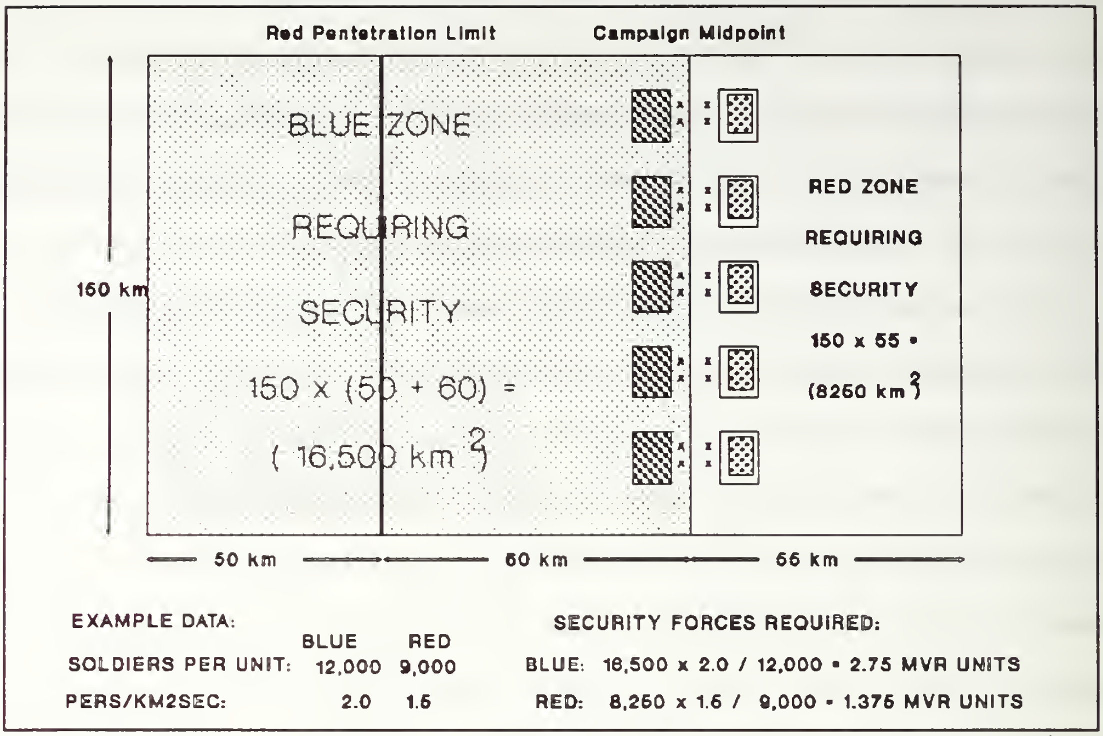

Figure 11. Geometric Interpretation for Determining Security Forces Required.

boundary until it reaches a penetration distance ending the campaign. MOSCOW determines a campaign midpoint corresponding to the location of the Red force front lines at half of total campaign time. The shaded area for each force represents the average zone area each side must secure during the campaign.

(BLUE or RED)PER/KM2SEC equals the number of soldiers per square kilometer required to secure the shaded area for each side discussed above. The calibration coefficients are multiplied by their respective shaded area to determine the total number of soldiers used for security. MOSCOW converts the total number of security soldiers to maneuver units required for security.

Selecting values for these two calibration coefficients is difficult because the process is represented in an awkward fashion. Model users are forced to select "soldier density" (the number of soldiers per square kilometer) which ultimately converts to maneuver unit requirements. Military operations planners determine security force requirements in quite a different manner, namely, by allocating units to security missions. In doing so, operations planners consider such factors as terrain type, logistical or support force vulnerability, overall mission, force structure, and risk to establish security forces.

The MOSCOW computation is given by:

$$\text{Security Force [MVR UNITS]} = (\text{zone width}) \times (\text{distance to campaign midpoint}) \times (\text{RED or BLUE PERS/KMSEC}) \times (\text{MVR UNITS/soldier}). \tag{23}$$

A MVR UNIT is the type of maneuver unit user defines in the model input section. MOSCOW uses MVR UNITS, each consisting of a number of vehicles and personnel, as the basic fighting element in the model.

Since this calculation can hardly be interpreted as representing an actual process of security force allocation, corresponding calibration coefficients are of equally dubious worth. One way to deal with this situation is to select calibration values which effectively eliminate the calculation of security forces from the model. This can be accomplished

by setting these values to zero. If other values are selected, model users are warned to closely examine the relative numbers of maneuver units used for engagements versus security requirements in model output.

PWRCOEFTGTAVAIL, cell L651.

In actual combat, firers are unable to engage some portion of the enemy force for a variety of reasons. For example, terrain provides concealment which "hides" targets, and also provides "cover" which "protects" targets. The use of terrain has the effect, then, of making some fraction the enemy unavailable as targets. In MOSCOW the user can select the base fraction of each force that is unavailable as targets to capture this effect. This base level of target availability is adjusted by several factors within the model. PWRCOEFTGTAVAIL determines the degree to which targets, previously unavailable, are made available due to the relative force ratio in an engagement. The idea is that the stronger force (in terms of numbers) makes a larger fraction of itself available as targets since there is more difficulty in concealing higher numbers of personnel and equipment. The effect of force ratio on target availability only affects the stronger force in MOSCOW. This process usually affects the attacker since the majority of scenarios involve a stronger force attacking a weaker defender.

Figure 12 demonstrates the use of PWRCOEFTGTAVAIL. The surface shows that as the force ratio increases, the more a stronger force's previously unavailable targets become available. The sensitivity of target availability to force ratio is determined by PWRCOEFTGTAVAIL. A smaller coefficient value means that target availability is very sensitive to force ratio. Larger PWRCOEFTGTAVAIL values imply that force ratio has little effect on target availability.

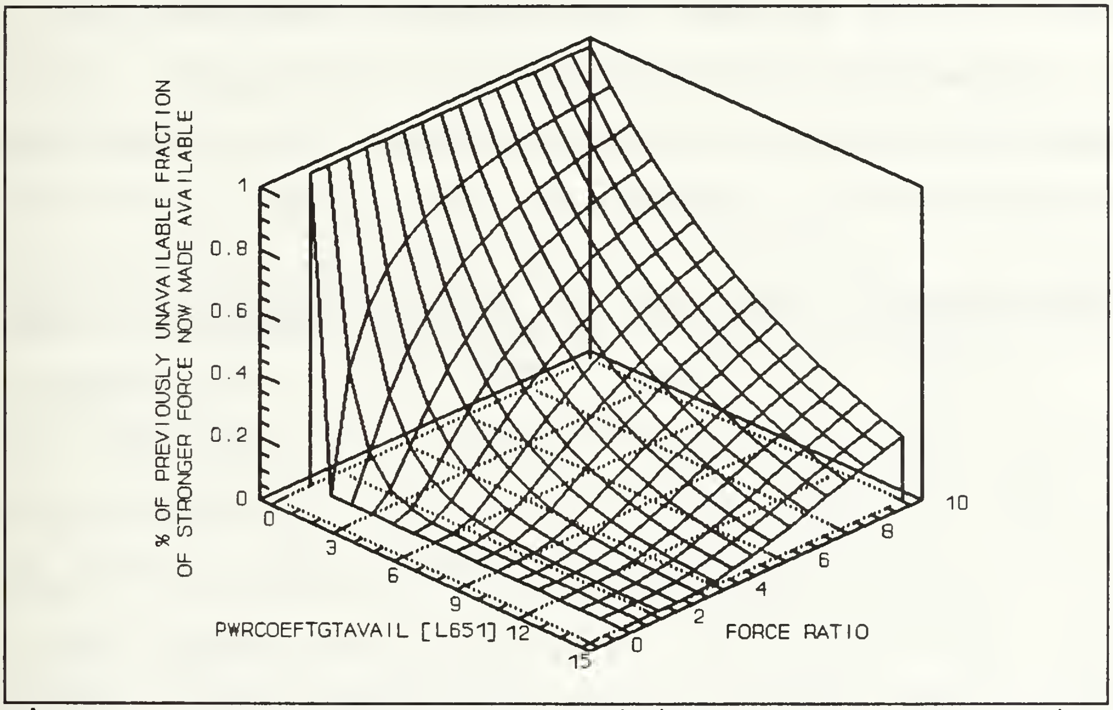

Figure 12. PWRCOEFTGTAVAIL Modifies the Degree to Which Force Ratio Makes More of the Stronger Force's "Hidden" Vehicles Available as Targets.

A range of values for PWRCOEFTGTAVAIL between about three and fifteen appear to be most reasonable for this process. Force ratio ought to have some effect, but not dominate all

other effects, such as terrain, which determine availability. For PWRCOEFTGTAVAIL values smaller than three target extremely sensitive to force ratio. For example, consider a unit that has is half of its vehicles available as targets before the effect due to force ratio. If the unit attacks at a 3 to 1 ratio advantage with a PWRCOEFTGTAVAIL value of 3, then the unit availability increases to over 96 percent. Such an increase in target availability due to force ratio alone is difficult to believe as being representative of the actual effect. Given the same unit, but using a PWRCOEFTGTAVAIL of 15, availability does not change from the original one half, demonstrating that coefficient values this large make availability very insensitive to force ratio.

PWRCOEFIERR-ATK, cell L654, and PWRCOEFIERR-DEF, cell L655.

In MOSCOW, users select a base level of intelligence (INTEL) error for Red and Blue forces. The input INTEL error is defined as the percentage of a unit's intelligence tasks that are not performed to their standard level. MOSCOW uses these inputs to capture the effect of intelligence error in combat. When units conduct all intelligence tasks to standard some amount of uncertainty about the enemy still exists. When some number of intelligence tasks are ill-performed the relative level of uncertainty increases, causing a loss in unit combat effectiveness. The effectiveness degraded in MOSCOW is in terms of lost opportunity, represented by

reducing the number of enemy targets a unit possessing intelligence error would otherwise be able to engage.

In the model, a unit's intelligence error reduces the fraction of the enemy available as targets. Unit effectiveness is degraded since units can only engage available targets. The general form of the equation is:

$$\text{\% Enemy Avail} = (\text{Previous \% Enemy Avail}) \times (1 - \text{INTEL error}) \qquad (24)$$

The remaining discussion deals with the term (1- INTEL error). This term is the multiplier which reduces the fraction of enemy targets available to a unit possessing intelligence error. The intelligence (INTEL) error is modified before being used in the above equation. The model treats intelligence error for attacking and defending units differently.

A defending unit's INTEL error is reduced by the Defend/Attack force ratio. The idea is that the degrading effect of intelligence error is reduced when the attacker uses a larger number of attacking units. The larger target array available to the defender mitigates the effect of INTEL error. The multiplier for defending units is:

$$\text{Attack Availability Multiplier} = 1 - [1 - (\text{defend/attack force ratio})^{\text{PWRCOEFIERR-DEF}}] \qquad (25)$$

which reduces attacker availability due to defender intelligence error.

Figure 13 shows the value for this multiplier for different force ratios and PWRCOEFIERR-DEF levels. The figure uses a defender intelligence error value of .10 for purposes of the example. A PWRCOEFIERR-DEF value of zero corresponds to the belief that force ratio has no effect on reducing defender intelligence error, therefore, the fraction of attack targets available to the defender remains at .90. Increasing PWRCOEFIERR-DEF values imply that force ratio has a stronger

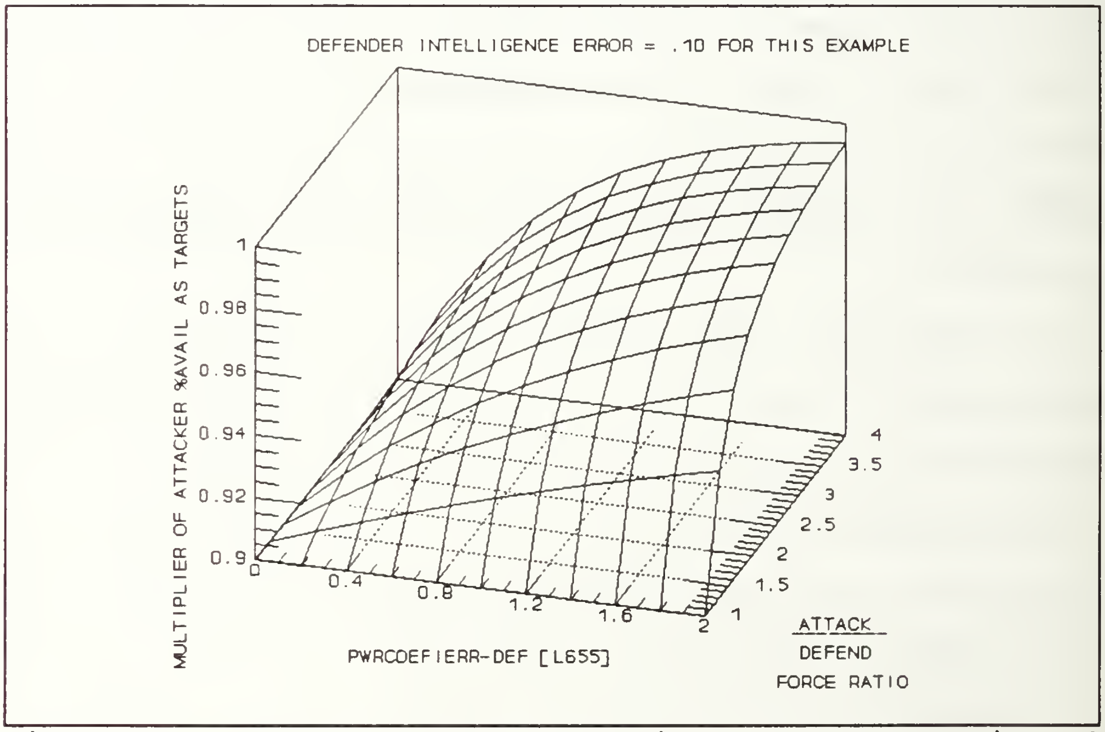

Figure 13. PWRCOEFIERR-DEF Determines How Force Ratio and Defender Intelligence Error Affect Attacking Force Availability as Targets.

effect in reducing defender intelligence error, so the fraction of attack targets available increases from .90. MOSCOW users may select any positive PWRCOEFIERR-DEF value, but values larger than two have about the same effect as using zero for INTEL error in the main input section. The recommended range for this calibration coefficient is from zero to two.

Attacking unit INTEL error is modified by a different factor. The idea is that the fraction of attacking targets available to the defender affects the amount of intelligence information collected. MOSCOW reduces the effect of intelligence error on the attacker when a larger fraction of the attacker is available to the defender. The equation representing this reduction is:

$$\text{Defender Availability Multiplier} = 1-[1-(\text{Fraction of attacker avail})^{\text{PWRCOEFIERR-ATK}}] \quad (26)$$

Figure 14 shows how the multiplier changes for different PWRCOEFIERR-ATK and force ratio combinations. This figure also uses an attacking force INTEL error value of .10 for example purposes. A value of zero for PWRCOEFIERR-ATK implies an attacker has no intelligence error, therefore, the multiplier remains at one regardless of the fraction of the attacker available. Increasing PWRCOEFIERR-ATK values imply larger fractions of the attacking force must be exposed in order to reduce an attacker's intelligence error.

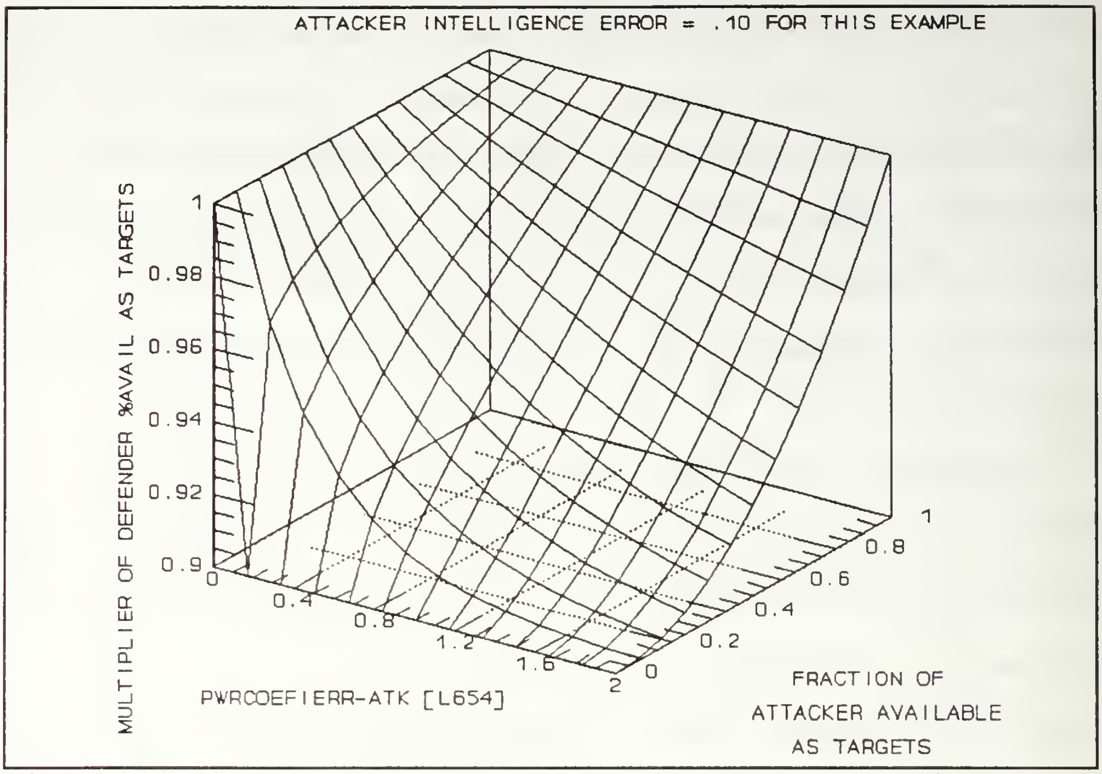

Figure 14. PWRCOEFIERR-ATK Determines How Attacking Force Exposure and Intelligence Error Affect Defending Force Availability as Targets.

The recommended range for PWRCOEFIERR-ATK is between zero and five. Values of zero mean that attack force intelligence error fails to decrease attacker effectiveness. Values greater than five have about the same effect as not using this optional coefficient.

PWRCOEFCASKIL, cell L657.

PWRCOEFCASKIL affects the degree to which supporting air and artillery kill rates change due to the enemy/friendly force ratio. If the enemy has a stronger force, the effects of friendly air and artillery are larger since there exists

a higher enemy target density. How much larger support effects become depends upon the value selected for PWRCOEFCASKIL. Only the weaker force's (normally the defender) kill rates are modified by this process. The air and artillery kill rates are multiplied by a factor of the form:

$$[\text{Enemy/Friendly Force Ratio}]^{\text{PWRCOEFCASKIL}}. \tag{27}$$

The force ratio must be greater than one or the factor is ignored in MOSCOW. Figure 15 shows the surface representing

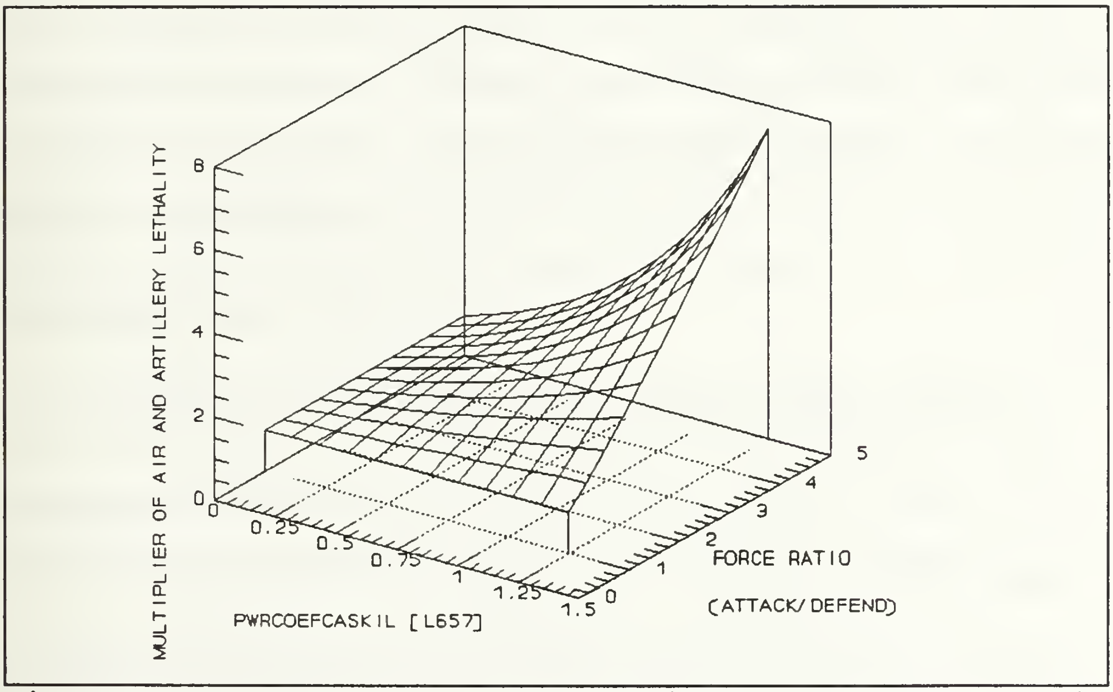

Figure 15. PWRCOFCASKIL Determines How Force Ratio (Representing Relative Target Density) Increases the Weaker Force's Air and Artillery Lethality.

this kill rate multiplier for various force ratio and PWRCOEFCASKIL values. The resulting kill rates are applied against enemy maneuver forces. Note that a value of zero for PWRCOEFCASKIL implies that a stronger force ratio has no effect in changing weaker force air and artillery kill rates. Calibration coefficient values greater than one increase support kill rates by unreasonably high factors, thus, the recommended range for PWRCOEFCASKIL is between zero and one.

PWRCOEFAIKILS, cell L660, PWRCOEFAIDEL, cell L663, and PWRCOEFAIDISR, cell L665.

These three coefficients work exactly as described for PWRCOEFCASKIL except that they apply only to air assets having air interdiction (AI) missions. PWRCOEFCASKIL applies to air assets performing close air support to ground maneuver. MOSCOW has inputs which describe what portion of total air assets are devoted to aerial interdiction missions. Aircraft involved in air interdiction are allocated to five mission types.

1. AI Attrition--sorties devoted to destroying enemy forces away from front line engagements.

2. AI Delay--sorties devoted to delaying enemy movement.

3. AI Disrupt--sorties devoted to disrupting command and control (increasing C3 error).

4. AI Counter HQ--sorties devoted to suppressing enemy air and artillery fires.

5. AI Supply--sorties devoted to destroying enemy supply capacity.

MOSCOW uses these three calibration coefficients to determine the degree to which the force ratio modifies the effect obtained in the first three AI missions listed above. The effect rate of each AI mission is multiplied by a factor exactly like that described in the section for PWRCOEFCASKIL. The only difference is that each of the AI missions has the effect described by their mission type. The following three figures show the use of each calibration coefficient with force ratio. The surface shape in each figure is identical to Figure 15 for PWRCOEFCASKIL. The units of measure in the vertical axis for Figures 16-18 describe the effects of each AI mission type. The recommended range for each of these three calibration coefficients is also between zero and one. They exist as separate coefficients so that model users can interpret differences in the way force ratio changes the effect of each mission type.

FRNTAGELETHCOEF, cell L667.

In actual combat, the defender has the advantage of occupying terrain that the attacker must seize in order to meet campaign objectives. The defender's advantage typically requires the attacker to mass more relative combat power to win the engagement. In MOSCOW, this process is modelled by reducing attacker lethality by some amount due to the defensibility of terrain.

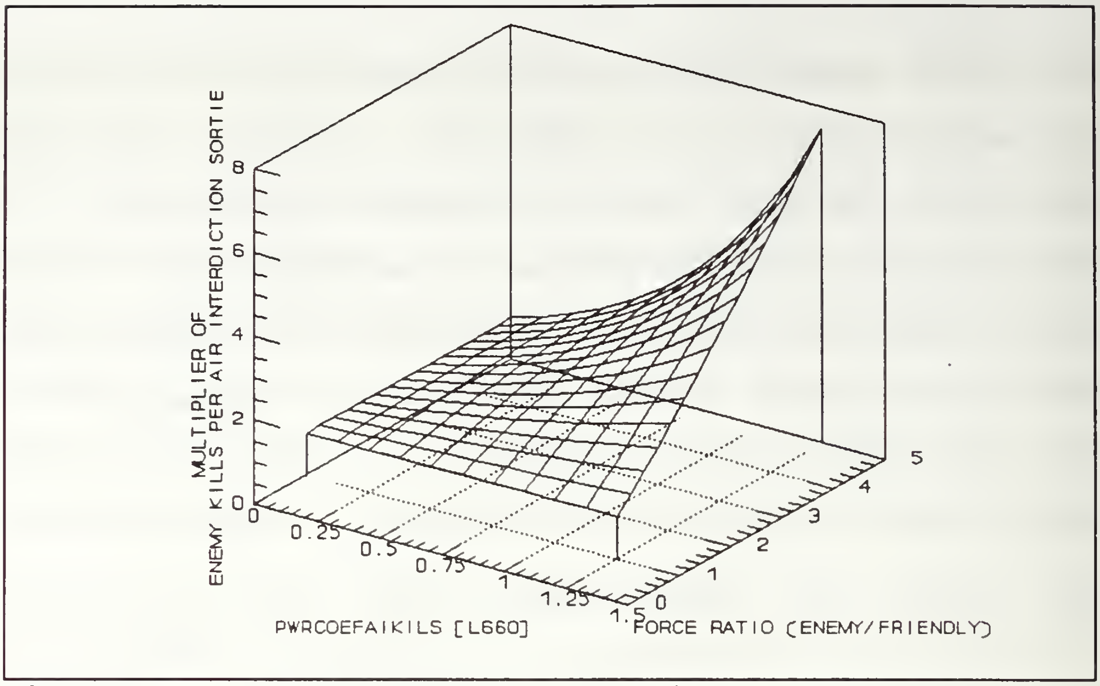

Figure 16. PWRCOEFAIKILS Determines How Force Ratio Modifies the Lethality of the Weaker Force's Aerial Interdiction Sorties.

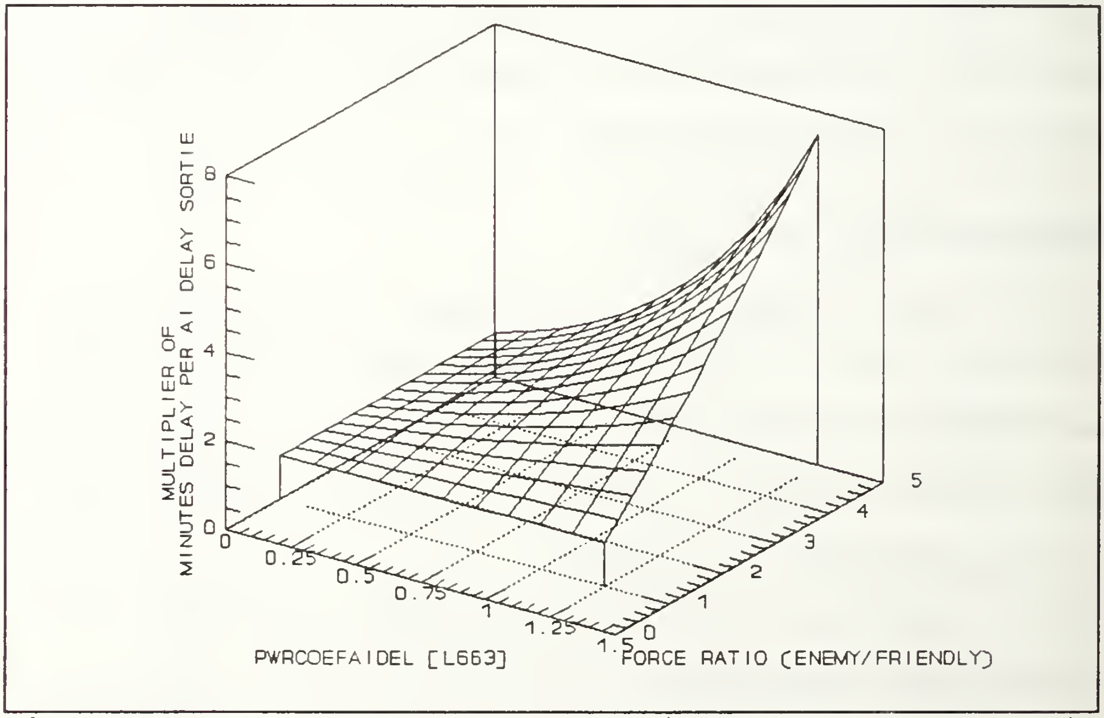

Figure 17. PWRCOEFAIDEL Determines How Force Ratio Modifies the Amount by Which the Weaker Force's Aerial Delay Sorties Delay Enemy Movement.

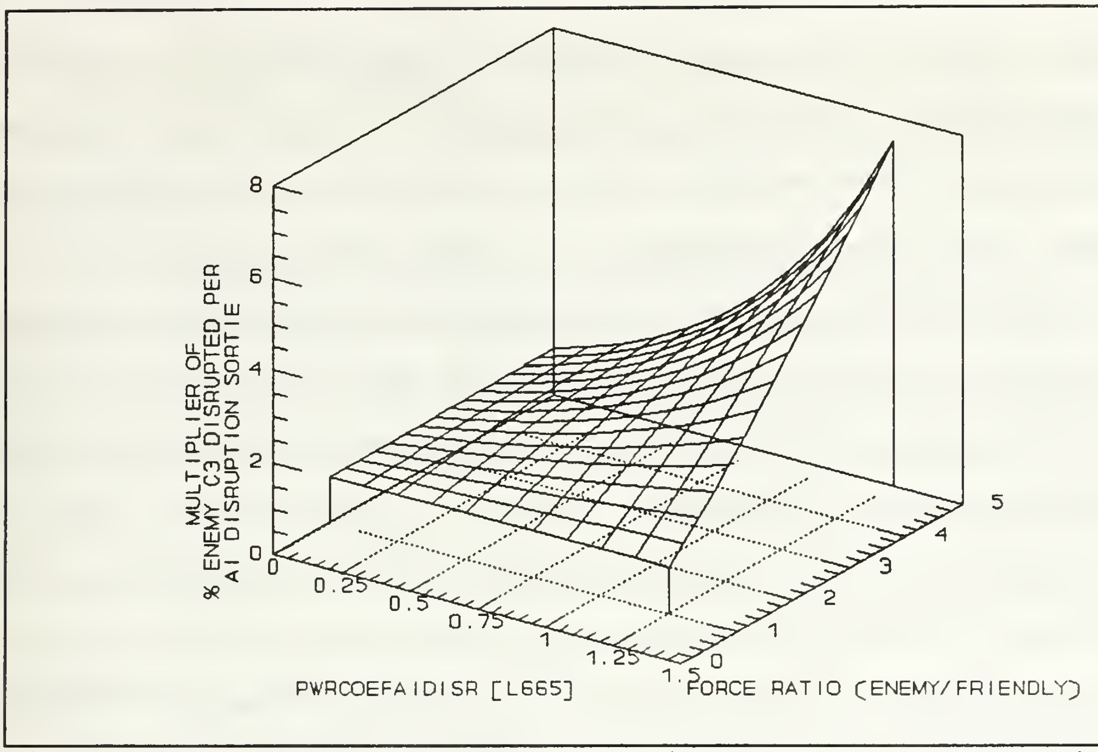

Figure 18. PWRCOEFAIDIS Determines How Force Ratio Modifies the Effect that the Weaker Force's Aerial Interdiction Sorties Have on Enemy C3 Error.

A set of terrain inputs includes a factor representing the defensibility of each type of terrain in the campaign zone. MOSCOW determines an harmonically weighted average of all terrain types and specifies an average terrain defensibility multiplier (TERRDEFMULT). Values for TERRDEFMULT start at one, representing no defense advantage, and increase from one as terrain defensibility improves.

The defender's advantage of occupying terrain is represented in MOSCOW by reducing attacker lethality by

$$\text{Attacker Lethality [enemy kills/min]} = \text{Previous Attacker Lethality} \times (1/\text{TERRDEFMULT}) \quad (28)$$

Note that increasing terrain defensibility increases TERRDEFMULT, producing a corresponding decrease in attacker lethality. The overall effect is to force the attacker to mass more relative firepower to defeat the defender.

There is an exception to this procedure when defenders attempt to defend a larger area than their capability allows. In this case, the defender is categorized as "overextended." MOSCOW monitors defending units to ensure that they are defending along a frontage within their capability. The defender loses some portion of its terrain advantage when overextended. MOSCOW represents this phenomenon by modifying the equation which reduces lethality to:

$$\text{Attacker Lethality [Enemy Kills/Min]} = \text{Previous Lethality} \times (\text{FRNTAGELETHCOEF}/\text{TERRDEFMULT}) \quad (29)$$

where FRNTAGELETHCOEF is a value greater than one.

FRNTAGELETHCOEF is a calibration coefficient which determines the amount a defender will lose terrain advantage by virtue of overextending its defense. The nature of this process limits the range of values that should be selected for FRNTAGELETHCOEF. Values for this coefficient should be greater than one; otherwise the effect of overextension would increase a defender's advantage. Conversely, values for this coefficient should be less than or equal to the value for TERRDEFMULT; otherwise the effect of overextension would add to the attacker kill rate. If the model user believes that

an overextended defender provides such an advantage to the attacker then choose a FRNTAGELETHCOEF which is greater than TERRDEFMULT.

The recommended range for FRNTAGELETHCOEF is between one and the existing value for TERRDEFMULT. When the user desires to use a FRNTAGELETHCOEF value equal to an unknown TERRDEFMULT value, type "T48" into spreadsheet cell L667. This technique automatically equates the calibration coefficient FRNTAGELETHCOEF to the one MOSCOW computes for TERRDEFMULT.

%REDBREAK/KM, cell L670.

This coefficient, as its name implies, is simply the percentage of Red force vehicles which "break down" for each kilometer of penetration. The process captured by this coefficient is that some fraction of combat vehicles are lost to equipment failure or some other noncombat cause. %REDBREAK/KM is a value multiplied against the Red Penetration Limit input to determine the total fraction of Red force vehicles lost by noncombat causes. The deeper the penetration limit (in kilometers) and the larger the value of %REDBREAK/KM, the more Red force vehicles are lost due to "breakdown." The effect is to reduce the total number of Red force vehicles that the Blue force must destroy during engagements to meet campaign success objectives. This reduction means less Blue force vehicles are needed to achieve

campaign success than would be required without the use of this coefficient.

The value selected for %REDBREAK/KM should normally be very small. Only a very small percentage of the Red force vehicle fleet should "break down" per kilometer. The model user should consider the scenario inputs for rate of Red advance and terrain types when selecting the coefficient value. Faster rates of advance and rugged terrain should imply a higher rate of Red break downs. The recommended value for %REDBREAK/KM is between zero and .10. A value of .10 implies that during a 100 km penetration the Red force loses a substantially large ten percent of its total strength due to breakdowns. Since these vehicles are never returned to the campaign, this rate seems to be a substantial cost for movement losses. Model users, however should apply whatever rate is supportable for a given scenario.

MILUSBLCOEF, cell L675.

In MOSCOW, the campaign is fought in a user defined rectangular zone. Inputs determine the terrain type mix within the zone. The mix of terrain types is converted into several factors representing the impact of terrain on lethality, vulnerability, and mobility. One of these factors, TERRMOVEMULT, is a factor (less than one) which reduces user input for Red and Blue vehicle movement speeds. TERRMOVEMULT also determines the fraction of the zone considered militarily

usable terrain. Only military usable terrain is occupied, attacked, or defended during the campaign.

The calibration coefficient MILUSBLCOEF determines the degree to which TERRMOVEMULT reduces the amount of military usable terrain area within the input campaign zone.

For example, the scenario may call for a zone of mixed terrain types 100 km wide and 150 km deep. Total area within the zone is 100 X 150 = 150,000 km^2. The mixed terrain inputs determine a TERRMOVEMULT factor of say, .80. This implies that combat vehicles travel only 80 percent of their input advance rates. Only a portion of the total zone area is usable by military forces. A value selected for the calibration coefficient MILUSBLCOEF effectively reduces the input zone width to some fraction of its original value of 100 km. This fraction is determined as follows:

$$\%\text{WIDTH-MILUSBL} = (\text{TERRMOVEMULT})^{\text{MILUSBLCOEF}} \qquad (30)$$

In MOSCOW, the actual portion of the campaign zone used by military forces is:

$$(\%\text{WIDTH-MILUSBL})\times(\text{zone width})\times(\text{zone depth}) = \text{ZONE AREA OF MILITARY USE } [\text{km}^2] \qquad (31)$$

Therefore, the relationship between TERRMOVEMULT and MILUSBLCOEF determines the fraction of the original campaign

zone used by military forces. Figure 19 shows such a relationship for all possible values of TERRMOVEMULT. As TERRMOVEMULT increases the fraction of the original zone available for military use also increases. A MILUSBLCOEF value of one implies that the value for TERRMOVEMULT is also the fraction of the original campaign zone which is of military use. Smaller MILUSBLCOEF values imply a weaker relationship and that zone usable fractions decrease more slowly than TERRMOVEMULT. MILUSBLCOEF values greater than one

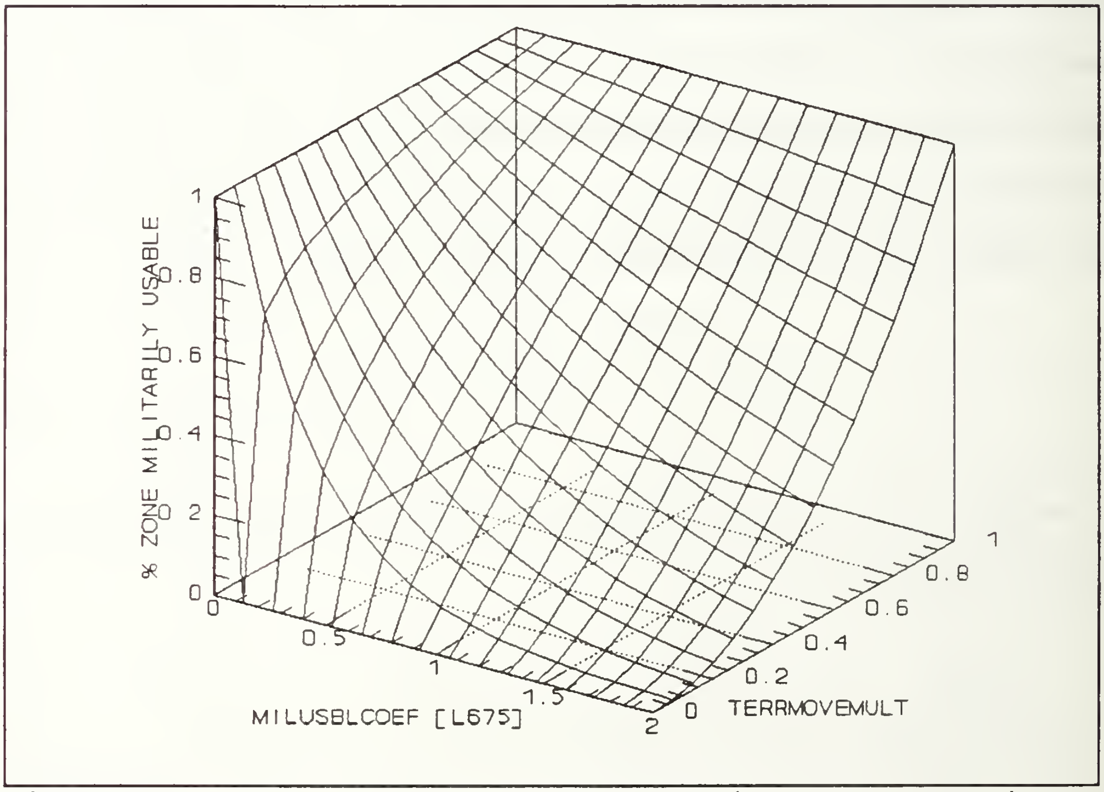

Figure 19. The Fraction of the Campaign Zone that is of Military Use is Determined by MILUSBLCOEF and TERRMOVEMULT.

imply a stronger relationship where zone usable fractions reduce faster than TERRMOVEMULT. MILUSBLCOEF values greater than two excessively reduce the usable portion of the campaign zone. For example, if movement is reduced by half (TERRMOVEMULT=.5), a MILUSBLCOEF of 2.5 reduces the militarily usable fraction of the entire zone to less than 20 percent. MOSCOW models campaigns which are fought by units which predominantly employ vehicle mounted weapons systems. A zone which is reduced like the example should be occupied by some form of unmechanized force and analyzed using a different model. The recommended value range for MILUSBLCOEF is between zero and two. Values in this range allow users to select the desired relationship.

<u>ATKTERMULTCOEF, cell L678.</u>

MOSCOW requires the user to input the mix of terrain types contained in the campaign zone. A terrain availability multiplier (TERRAVAILMULT) is one of several factors which MOSCOW determines from terrain inputs. The terrain availability multiplier (between zero and one) is the fraction of the total force which is available as targets. The value (1 - TERRAVAILMULT) represents the fraction of each force that is not available as targets due to terrain.

The calibration coefficient ATKTERMULTCOEF is used to account for the phenomenon that an attacking force, by virtue of its aggressive mission, receives less protection from

terrain than the defender. In MOSCOW, this phenomenon is captured by reducing the fraction of the attacking force not available as targets:

$$\text{Fraction not available} = \frac{(1 - \text{TERRAVAILMULT})}{\text{ATKTERMULTCOEF}} \tag{32}$$

where ATKTERMULTCOEF is a value greater than or equal to one.

In MOSCOW, Lanchester lethality coefficients (enemy kills/firer x minute) are reduced by the fraction of enemy targets available. This represents the idea that a force can only mass fires on available targets. The effect of the calibration coefficient ATKTERMULTCOEF in MOSCOW is to increase the fraction of the attacking force available as targets to the defender. Lethality coefficients are adjusted as follows:

$$\text{Defender Lethality}\left[\frac{\text{Enemy Kills}}{\text{Firer} \bullet \text{Min}}\right] =$$

$$\left\{1 - \frac{(1 - \text{TERRAIN AVAIL MULT})}{\text{ATKTERMULTCOEF}}\right\} \times \text{Previous Lethality} \tag{33}$$

$$\text{Attacker Lethality}\left[\frac{\text{Enemy Kills}}{\text{Firer} \bullet \text{Min}}\right] =$$

$$\{1 - (1 - \text{TERRAIN AVAIL MULT})\} \times \text{Previous Lethality} \tag{34}$$

These equations show that the defender's lethality is reduced by some smaller amount than the attacker. Figure 20 graphically illustrates the degree to which the equations differ due to the calibration coefficient ATKTERMULTCOEF. In the figure, the edge of the surface at a value of one for ATKTERMULTCOEF is the edge where the attacker and defender lethality are reduced by the same fraction. In other words, terrain protection has the same effect on both forces. Selecting values for ATKTERMULTCOEF greater than one means that attacking forces receive less protection from terrain, increasing their availability as targets, and subsequently reducing defender lethality by a smaller amount than the standard reduction.

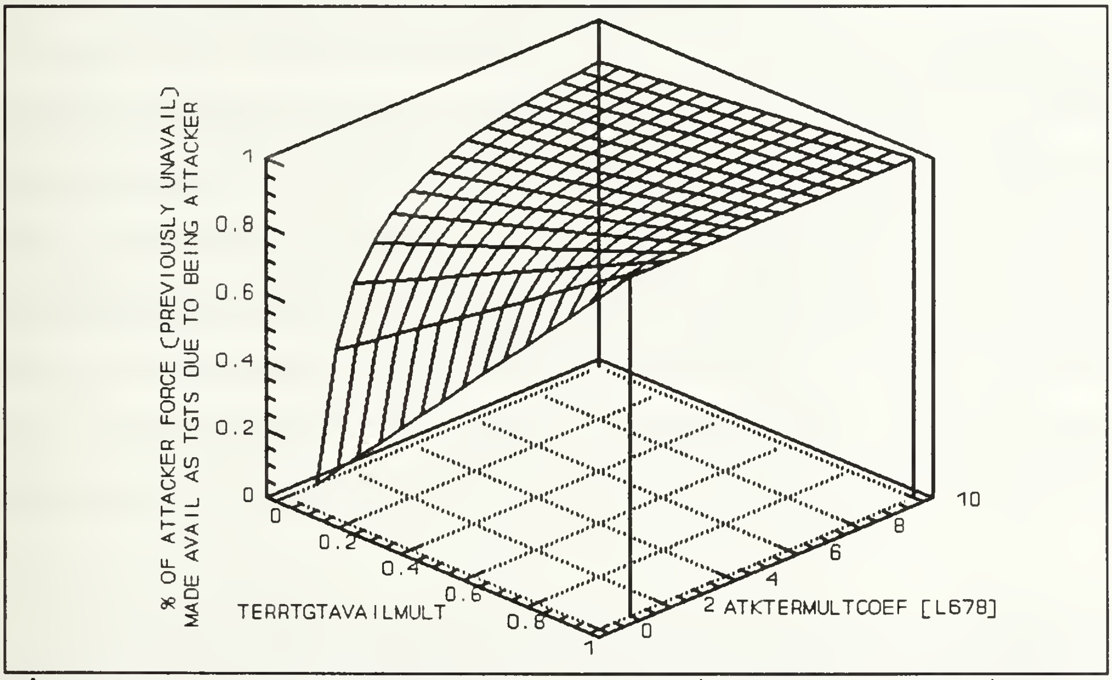

Figure 20. ATKTERRMULTCOEF Determines the Fraction of Terrain Protection Lost by the Attacker, Increasing the Fraction of Attacking Vehicles Avaialable as Targets.

The recommended range from which to select values for ATKTERMULTCOEF is between one and five. Values below one do not make sense since they imply that terrain makes more attacking targets available than exist in the attacking force. The figure also shows that values greater than five incorrectly imply that terrain affords almost no protection to the attacker.

DISMTDVULNCOEF, cell L683.

MOSCOW allows users to input the fraction of Infantry conducting dismounted operations in an average engagement. The net effect is to increase force lethality due to the increased number of firers at a cost of increasing firer vulnerability. MOSCOW employs a homogeneous Lanchester attrition module, so dismounted Infantry effects must be represented indirectly. Lanchester lethality coefficients, [enemy kills/firer x minute], apply to vehicle weapon systems. The model tallies some fraction of a vehicle's crew as killed when their vehicle is destroyed. Infantry dismounted from a vehicle and subsequently killed are counted separately by transforming the vehicle kill rate into a personnel kill rate using the input ANTIPERSCOEF. This is the personnel kill rate applied only to the portion of Infantry that is conducting

dismounted operations.[4] The equation computing dismounted Infantry kills is:

$$\text{Dismounted Infantry}\left[\frac{\text{Kills}}{\text{Min}}\right] =$$

$$\left\{\frac{\text{Vehicle Kills}}{\text{Min}}\right\} \times \text{ANTIPERSCOEF} \times (\%\text{PERSDISMTD})^{\text{DISMTDVULNCOEF}} \tag{35}$$

where %PERSDISMTD is the fraction of Infantry conducting dismounted operations. The input value for ANTIPERSCOEF is difficult to determine. This input is the number of dismounted Infantry kills (given that all Infantry is dismounted) that can be expected for every vehicle kill under exposed conditions. The resulting personnel kill rate is then adjusted by the relationship between %PERSDISMTD and the calibration coefficient DISMTDVULNCOEF.

Figure 21 demonstrates the effect of this relationship on the dismounted Infantry kill rate. A value of one for DISMTDVULNCOEF implies that the "exposed condition" kill rate is applied to dismounted Infantry. Increasing values for DISMTDVULNCOEF imply less exposure and a smaller Infantry kill

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[4]It is interesting to note that as a result of MOSCOW's use of inputs which aggregate the characteristics of equipment types, each MOSCOW "average" vehicle has the capability to dismount Infantry so long as some dismountable Infantry exists within the underlying scenario.

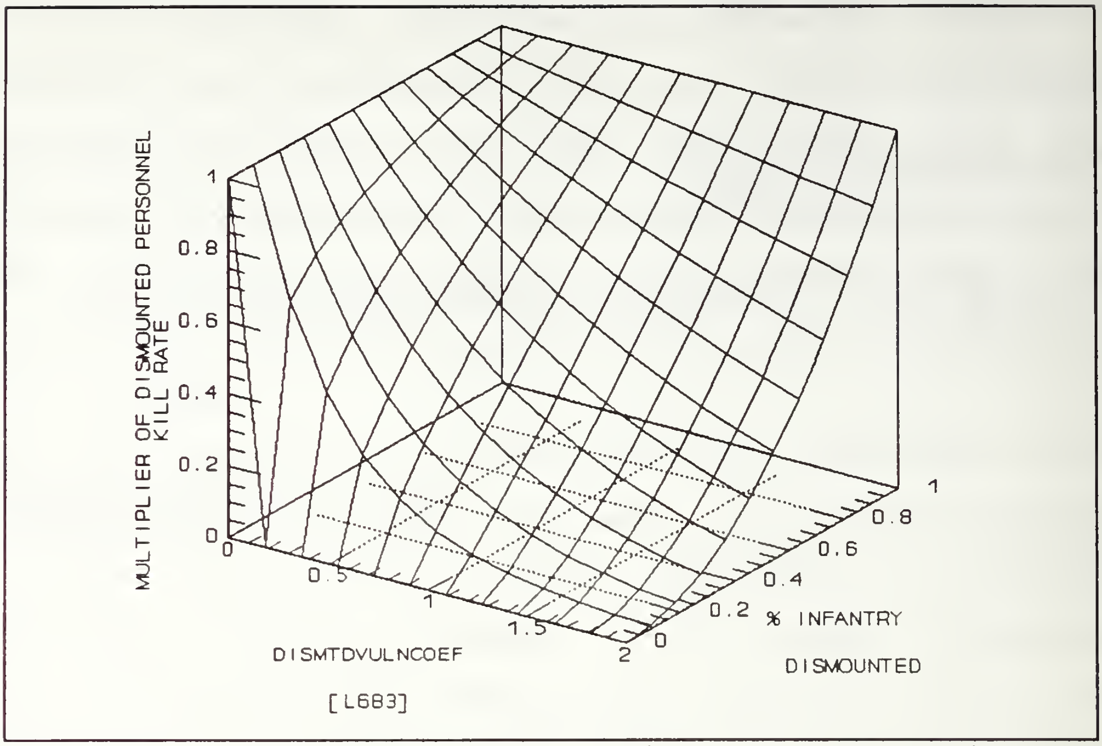

Figure 21. DISMTDVULNCOEF Determines the Vulnerabilty of Dismounted Infantry.

rate. For example, a coefficient of 2.5 applied to a situation where half of all Infantry is dismounted implies that Infantry casualties occur at less than one fifth of the normal "exposed" rate. A reduction of this magnitude seems excessive so the recommended upper limit is two. Model users may represent some situations requiring larger values, but on average, this is a significant reduction. This Note that DISMTDVULNCOEF values less than one are feasible, but mean that the fraction of Infantry dismounted are killed at a rate exceeding that defined by the input ANTIPERSCOEF which violates the intent of the process. The recommended range for DISMTDVULNCOEF is between one and two.

DISMTDLETHCOEF, cell L685, and IERRCOEFSURVTM, cell L690.

These two coefficients are used as examples in the main body of this paper and are not repeated here. See Chapter II, Section B, for an explanation of IERRCOEFSURVTM and Chapter III, for an explanation of DISMTDLETHCOEF.

HQLOADDELCOEF, cell L692, and HQBURDDELCOEF, cell L694.

Both of these calibration coefficients are used to determine the time forces spend in the Delay activity. The Delay activity represents wasted time subordinate units spend "awaiting orders" rather than other combat activities. The phenomenon represents the "friction of command" a delay induced by headquarters elements which control several, possibly too many, subordinate maneuver units. Military headquarters elements are designed to control a certain maximum number of subordinate units.[5] As the number of subordinate units increases, even within design limits, headquarters elements take longer to coordinate and issue orders for execution. The term "load" denoted by the coefficient name, refers to this phenomenon. The term "burden" refers to the idea that headquarters will take even longer to coordinate subordinate activities when the number of units it commands exceeds its design limit.

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[5]This maximum number is often referred to as a headquarter's "span of control" which is a consideration in the optimum design of force structure (number and types of units) and the operational concept through which these forces are used.

MOSCOW users input the number of Blue forces available to achieve desired success conditions. Among other values are inputs which specify the number of available headquarters and their design limit for command, or HQ-SPAN MVR. These values determine headquarters load and burden. As headquarters load and burden increase, time spent in the Delay activity increases. Increased delay time results in the use of additional Blue units. This compounds the load and burden problem of controlling headquarters.

The equation used to determine the time spent in the delay activity is:

$$\text{Time Delay [Days]} =$$

$$\left(\frac{\text{Units Required}}{\text{HQ AVAIL}}\right)^{\text{HQLOADDELCOEF}} \times \left[\frac{\left(\frac{\text{Units Required}}{\text{HQ AVAIL}}\right)}{\text{HQ-SPAN MVR}}\right]^{\text{HQBURDDELCOEF}} \quad (36)$$

where "Units Required" is the number of maneuver units required to achieve success, HQ AVAIL is the number of available headquarters, and HQ-SPAN MVR is the design limit for the number of units a headquarters can adequately command. The number of Blue (Units Required) is calculated as part of model output.

The calibration coefficients used in the above equation transform units-to-headquarters ratios and related design limits to delay time. Figures 22 and 23 provide examples demonstrating the effect of the two coefficients. In both

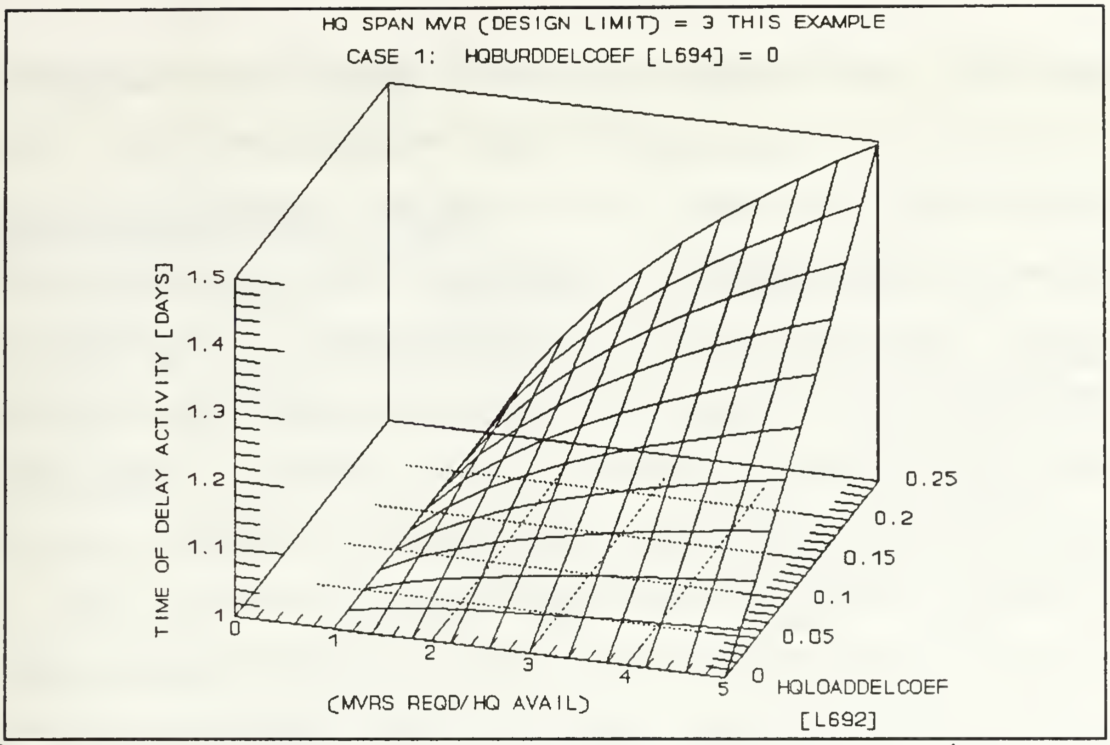

Figure 22. Example of How HQLOADDELCOEF Affects Time of the Delay Activity When HQBURDDELCOEF = 0.

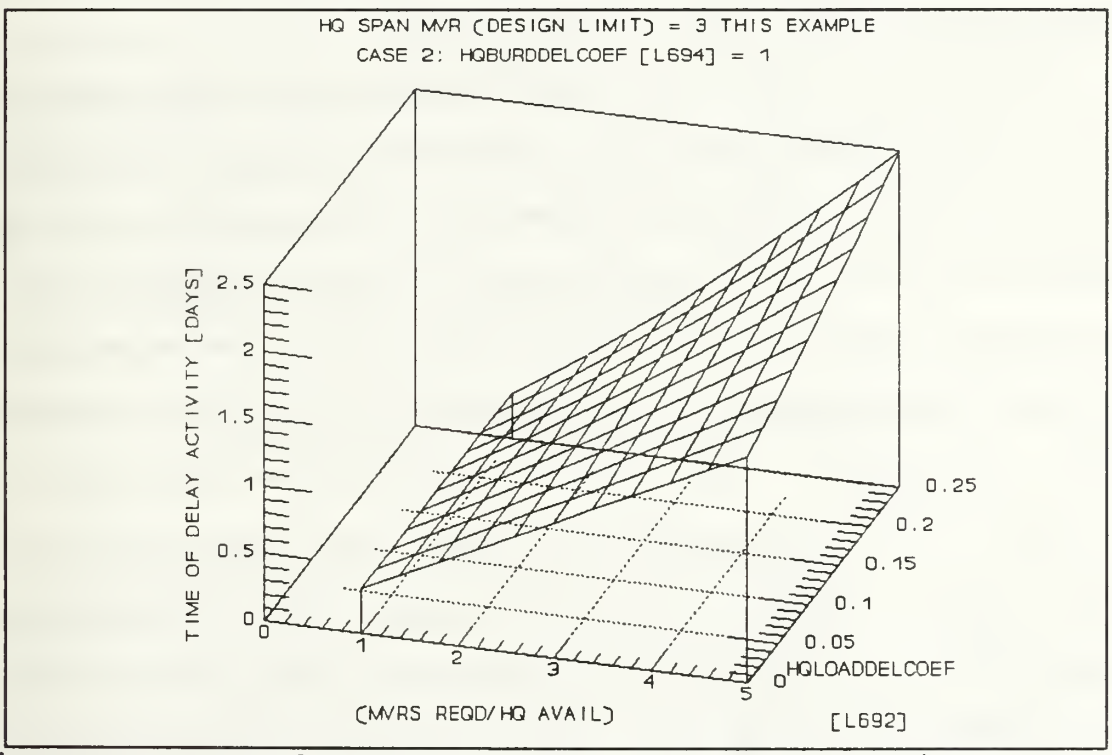

Figure 23. Example of How HQLOADDELCOEF Affects Time of Delay Activity When HQBURDDELCOEF = 1.

examples, headquarters units are capable of adequately commanding three subordinate units (HQ-SPAN MVR = 3). Both figures show the effect of varying MVR REQD/HQ ratios and values for HQLOADDELCOEF. Comparing the two figures provides insight about the effect of HQBURDDELCOEF. In Figure 22 HQBURDDELCOEF is set at zero which implies that headquarters design limits have no effect on delay activity. This figure shows only the effect of HQLOADDELCOEF. Figure 23 is the alternate extreme case where HQBURDDELCOEF is set at one. In this case headquarters design limits have their maximum effect on delay activity time. Note that this case provides more extreme values for delay activity time. Values above one for HQBURDDELCOEF result in excessive delay periods when headquarters exceed their design limits.

Recommended values for HQLOADDELCOEF range from zero to 0.25. For HQBURDDELCOEF the recommended range is from zero to one. These ranges are recommended so that delay times for current force structure headquarter's "span of control" (3-5) and typical numbers of assigned units (1-5) seem reasonable. The computed delay time is assessed against every unit between every engagement. Although delay time is difficult to quantify, it is reasonable to expect that some delay will exist, but on average, not in excess of 2.5 days between each engagement. Selecting calibration coefficient values within the recommended range for current force structure standards keeps delay time within these limits. Users are cautioned to

carefully examine model output to establish that time spent in the Delay activity is reasonable.

HQBURDCOEFC3ER cell, L696.

MOSCOW initially determines the number of Blue units required to achieve campaign success while ignoring command, control, and communications (C3) error. The model then determines how many additional Blue units are required to overcome inefficiency associated with the level of C3 error. C3 error is a fractional level of command, control and communications degradation.

The calibration coefficient HQBURDCOEFC3ER is used along with headquarters burden to modify the level of C3 error before it is used to determine additional Blue units. Headquarters burden, described in detail in the section for HQBURDDELCOEF, represents the effect of headquarters units commanding some number of subordinate units above or below their intended design limit. The modified level of C3 error is established in the following equation.

$$\text{Operational C3 Error} = (\text{C3 Error}) \times (\text{HQ Burden})^{\text{HQBURDCOEFC3ER}} \qquad (37)$$

HQ Burden is a value usually between 0.5 and 1.5, depending upon the number of units it commands. Headquarters which are commanding half as many units as they are designed for produce a HQ Burden of 0.5. Headquarters that command

twice as many units (highly unlikely) as they are designed for produce a HQ Burden of two. MOSCOW computes HQ Burden as the average burden for all headquarters in the campaign. Values greater than one imply overburdened headquarters and increase C3 error. Values less than one imply under burdened headquarters and decrease C3 error. The degree of C3 error modification by HQ Burden depends upon the value selected for the calibration coefficient HQBURDCOEFC3ER. Figure 24 shows how various calibration coefficient and HQ Burden combinations combine to modify the original C3 error level. When headquarters are commanding at their design limits C3 error

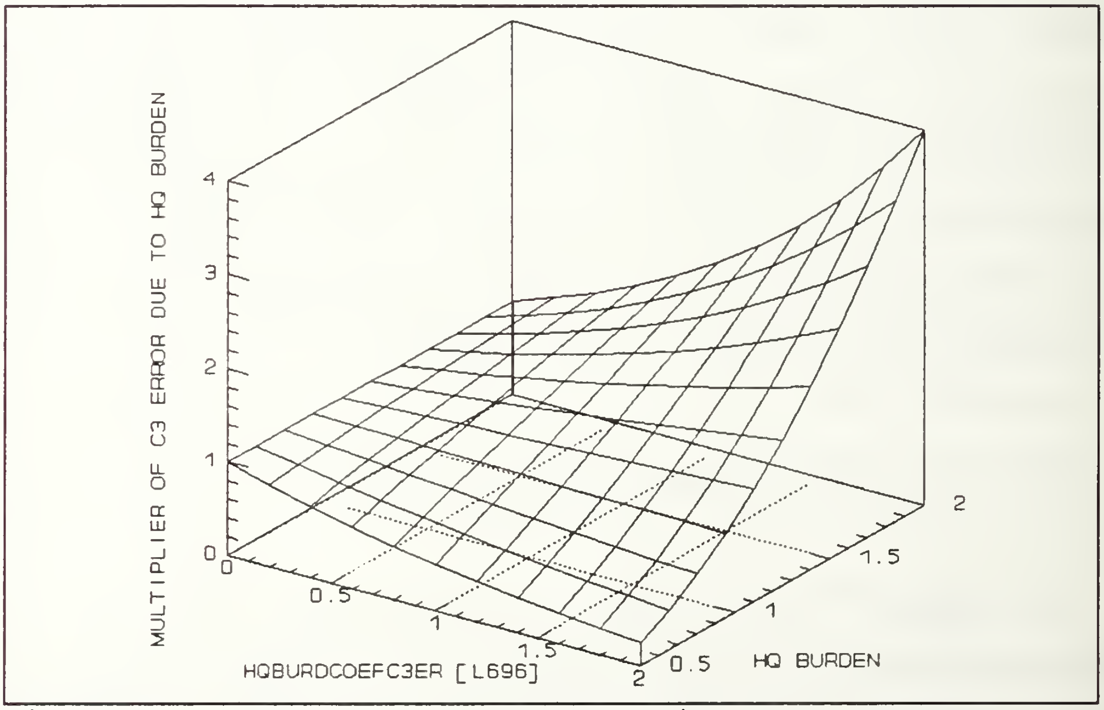

Figure 24. HQBURDCOEFC3ER Determines How Headquarters Burden Affects C3 Error.

is not modified, regardless of the calibration coefficient value. A value of zero for HQBURDCOEFC3ER means that C3 error is not affected by headquarters burden. Larger calibration coefficient values impart larger modifications to C3 error when headquarters are under or overburdened.

The recommended range for HQBURDCOEFC3ER value selection is from zero to two. Values above two for this coefficient result in unreasonably high C3 error increases when headquarters are overburdened. For example, a coefficient value of three applied to headquarters burden of 1.3 more than doubles C3 error. This is equivalent to a headquarters with a rated span of three controlling one extra unit (four) at a cost of doubling C3 error. This relationship is too strong for most scenarios.

REDSURVDISCOEF, cell L701.

In MOSCOW the Disengage activity represents the time Blue forces spend disengaging from combat and travelling some "shadow" distance from the enemy. When a unit has complete control over the disengagement, time spent in this activity is the time it takes to travel the shadow distance at an unimpeded movement rate. In most cases, neither side has complete control over the disengagement and movement is impeded by enemy survivors. The calibration coefficient REDSURVDISCOEF modifies the amount by which Red survivors increase unimpeded Blue attacker disengagement time. The

Disengage activity time is determined by the following equation:

$$\text{Time to Disengage [Days]} = \left(\frac{\text{Disenagement Distance}}{\text{Movement Rate}}\right) +$$

$$\left(\frac{1}{\text{REDSURVDISCOEF}}\right) \times (\%\text{REDSURVIVORS})^{\left(\frac{1}{1-\text{DISENAGE\%-ATK or DEF}}\right)} \quad (38)$$

DISENG%-ATK or DEF is a value between zero and one representing Blue force ability to control disengagement. The user selects two values, one for each engagement type of attack or defend. A value of one for this input indicates that Blue has full control during disengagement. A value of zero implies that Red controls disengagements. The equation shows that the fraction of the original Red force remaining also effects the time Blue takes to disengage. Note that when Blue has total control over the disengagement, time to disengage is effectively unimpeded travel time. Figure 25 shows how the calibration coefficient REDSURVDISCOEF scales unimpeded travel time for Blue. The figure does not include the impeded travel time, since it is a constant for any given scenario. For purposes of the example, the figure uses a value of 0.75 as the fraction of the Red force surviving the engagement.

Increasing calibration coefficient values decrease the ability of surviving Red forces to impede Blue disengagement.

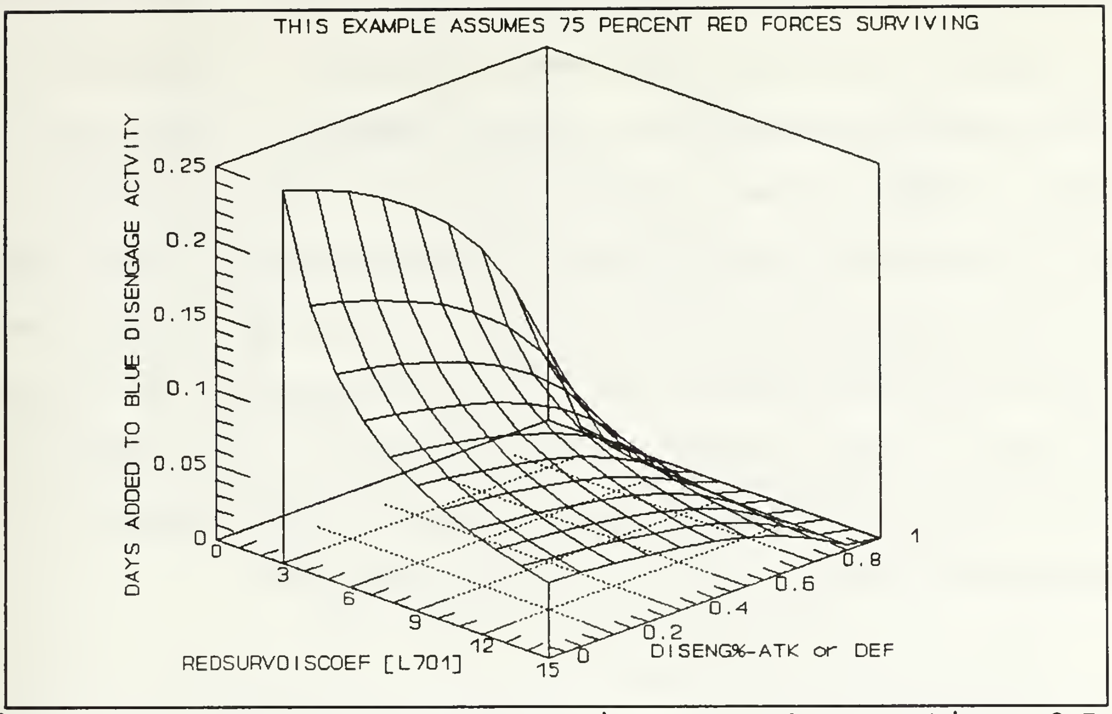

Figure 25. REDSURDISCOEF Determines How the Fraction of Red Survivors and Blue Force's Ability to Control Disengagement Add to the Time Blue Takes to Disengage.

The recommended REDSURVDISCOEF value range is between three and fifteen. Values smaller than three produce unreasonably high disengagement times for Blue. Values larger than fifteen make Blue disengagement time insensitive to Red survivors, even when Red controls disengagement. Model users are advised to evaluate disengagement times after each run to ensure the activity does not dominate other activities in the cycle.

RECONSTMCOEF, cell L703.

Units must assess casualties to personnel and equipment and reorganize between engagements. MOSCOW models this process by making units spend time in the Reconstitute

activity. The primary variables MOSCOW uses to determine the time spent in this activity are the fraction of the Blue force which survives engagements and the amount of Blue force C3 error. After longer engagements the time to change from battle formations to administrative postures is also added, but not explained in this section. The idea is that more casualties and higher C3 error rates both serve to increase the time a force needs to reconstitute. The calibration coefficient RECONSTMCOEF scales the following equation to a reasonable time for the Reconstitute Activity.

$$\text{Time to Reconstitute[Days]} = \frac{\text{RECONSTMCOEF}}{(1 - \text{C3 ERROR}) \times (\text{\%BLUE SURVIVORS in ATK or DEF})} \qquad (39)$$

The argument %Blue Survivors is a different value for attack and defend engagements. This equation is plotted in Figure 26 for various levels of the numerator and denominator. The combined term in the denominator should range between 0.4 and 0.9 for reasonable engagement attrition and C3 error levels. The larger the value for RECONSTMCOEF, the longer the time spent in the Reconstitute activity. Time is spent in this activity between each engagement. Recommended values for RECONSTMCOEF are between zero and 0.1. A value of zero implies that the user does not want to model reconstitution time for a given scenario. Values greater than 0.1 lead to excessively large average reconstitution activity times.

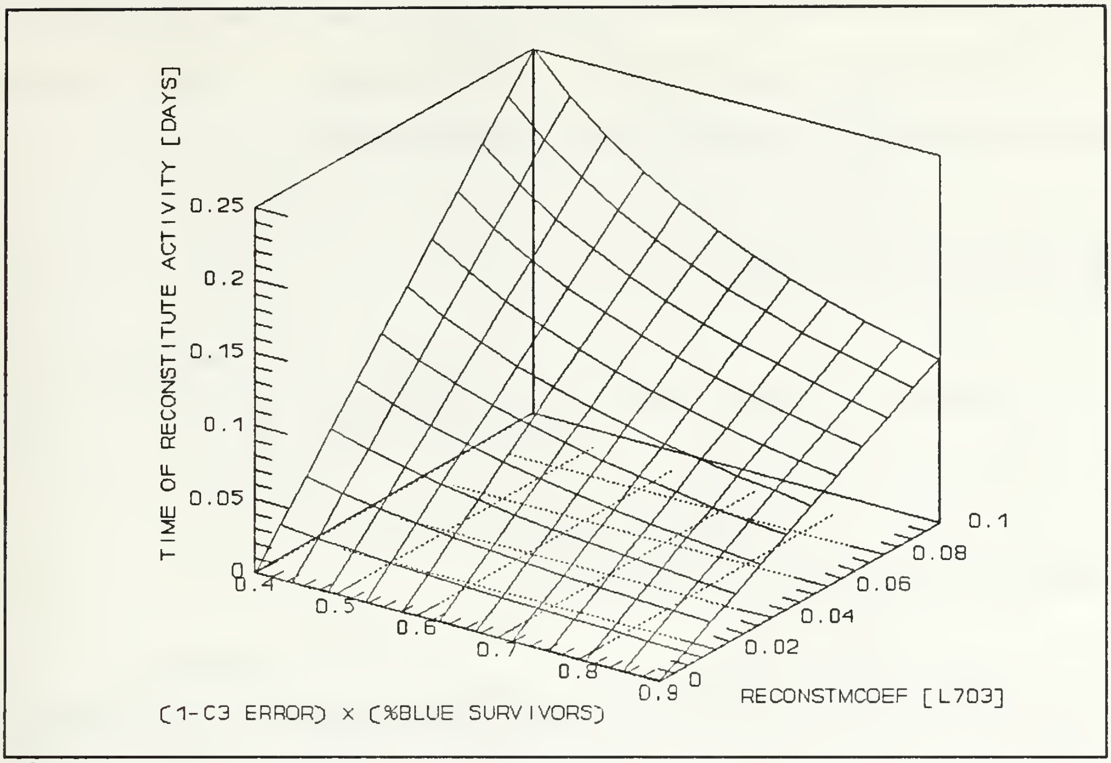

Figure 26. RECONSTMCOEF Determines How C3 Error and the Fraction of Blue Survivors Combine to Determine Time to Reconstitute Blue Forces.

LOWRESTCOEF, cell L708.

Lack of rest degrades the effectiveness of forces in combat. In MOSCOW, users select a value, BASELINE%REST, which represents the fraction of a day soldiers must rest to maintain full effectiveness. Model users also select a value, %REST, which represents the fraction of a day soldiers actually rest during the modelled campaign. When %REST equals or exceeds BASELINE%REST, force effectiveness is not degraded. If %REST is below BASELINE%REST, soldiers fail to get adequate rest and effectiveness decreases. Two Blue force attributes are degraded by lack of rest: movement rate and Lanchester lethality kill rates. The degree to which lack of rest

degrades these attributes depends upon the value selected for the calibration coefficient LOWRESTCOEF. The equations modifying these attributes are as follows:

$$\text{Blue Movement Rate}\left[\frac{\text{KM}}{\text{Hour}}\right] =$$

$$\text{Previous Movement Rate} \times \left(\frac{\%\text{REST}}{\text{BASELINE}\%\text{REST}}\right)^{\text{LOWRESTCOEF}} \qquad (40)$$

$$\text{Blue Kill Rate}\left[\frac{\text{Enemy Kills}}{\text{Firer} \bullet \text{Min}}\right] = \qquad (41)$$

$$\text{Previous Kill Rate} \times \left(\frac{\%\text{REST}}{\text{BASELINE}\%\text{REST}}\right)^{\text{LOWRESTCOEF}}$$

The term degrading the full rest rates is plotted in Figure 27. As expected, a unit's effectiveness decreases as rest decreases below the baseline threshold. A LOWRESTCOEF of zero implies that lack of rest effects are not modelled. As the value for LOWRESTCOEF increases, lack of rest effects become more severe. The recommended range of values for this coefficient is between zero and five. Values larger than five excessively degrade both movement and lethality.

__CALIBRATION COEFFICIENT, cell L711.__

This calibration coefficient value is input in spreadsheet cell L711, but has no established name. The value selected for this calibration coefficient determines the degree that Red C3 error is reduced by the relative time Red spends in

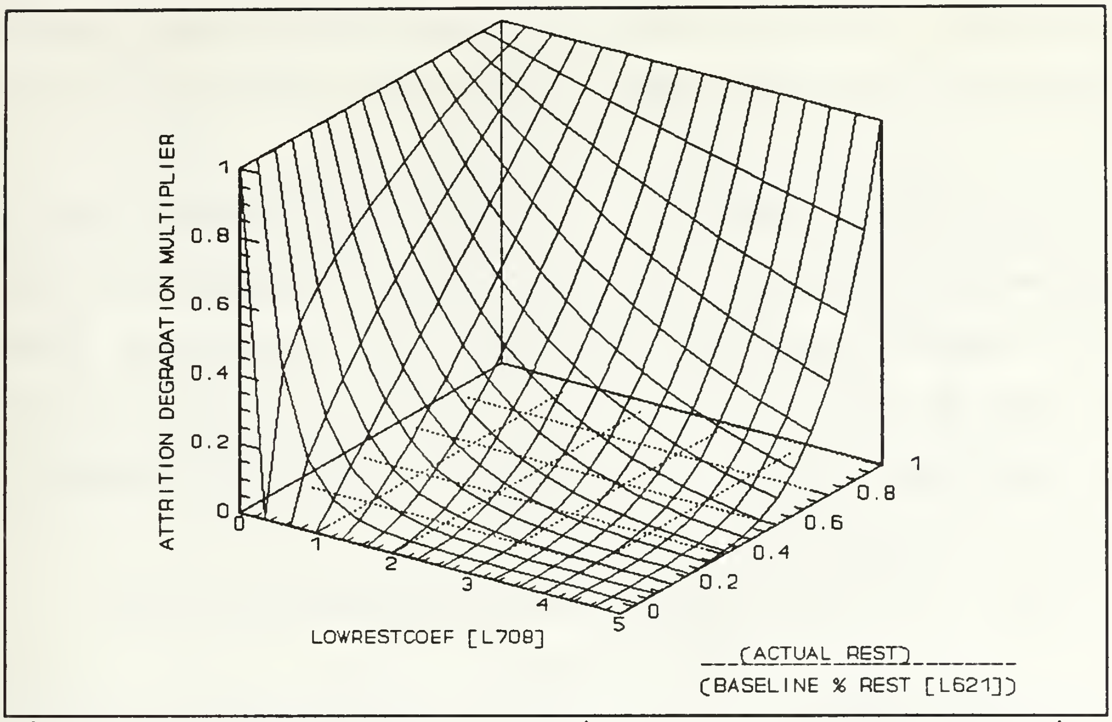

Figure 27. LOWRESTCOEF Determines How Much Blue Lethality is Degraded by Lack of Rest.

activities requiring no movement or combat. MOSCOW establishes a distribution of activity times Blue forces spend between each engagement event. MOSCOW determines the fraction of a total cycle of these activities that Blue spends not moving or in combat and places this value in a variable named BLUE%NON-M/C. This is the fraction of a cycle between engagements Blue spends in non-moving activities. MOSCOW does not compute a corresponding fraction of total time not moving for Red forces. The user input RED%NON-M/C establishes the corresponding fraction of the total time Red spends in activities not involving advance or combat. The ratio (RED%NON-M/C / BLUE%NON-M/C) establishes a relative amount of

nonmovement activity between Red and Blue forces. When Red forces move more than Blue forces, this ratio is less than one.

Red C3 error reduces both the Red force movement rate and Lanchester lethality kill rates. MOSCOW allows Red C3 error to be reduced when Red forces move more than Blue forces. The idea is that the more Red out-maneuvers Blue, the more Red can overcome the degradation effects of C3 error on movement rate and lethality.

Red C3 error is reduced by the following equation:

$$\text{RED C3 ERROR (\%)} = \text{Previous RED C3 ERROR} \times \left(\frac{\text{RED\%NON-M/C}}{\text{BLUE\%NON-M/C}} \right)^{L711} \tag{42}$$

Red C3 error is only modified when the nonmovement ratio is less than one; in other words, when Red moves more than Blue. The value selected for calibration coefficient L711 determines the degree to which relative Red movement reduces Red C3 error. The amounts of reduction for various movement ratios and L711 values are plotted in Figure 28.

In this graph, the movement ratio axis ranges from 0.2 to one. This corresponds to Red movement from almost double that of Blue to the same amount. When Red moves the same amount as Blue, no adjustment is made to C3 error. As Red forces move more than Blue, Red C3 error decreases. The amount of C3 error reduction increases as the calibration coefficient

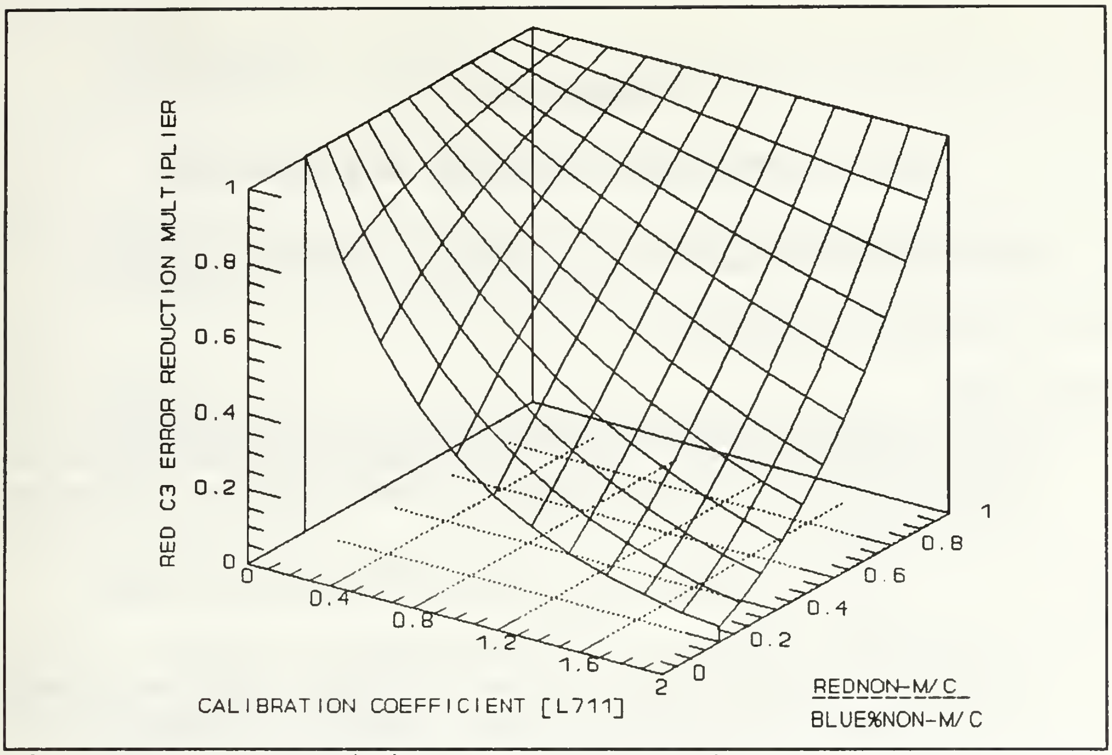

Figure 28. Coefficient L711 Determines How Red-to-Blue Relative Movement Affects Red C3 Error.

L711 increases. Note that a value of zero for L711 implies that the model user assumes that Red forces may not reduce C3 error by movement.

The recommended range for calibration coefficient L711 is between zero and two. Values larger than two excessively reduce Red C3 error.

APPENDIX C

CODE CORRECTIONS CONTAINED IN MOSCOW-NPS

A. Code Changes Affecting Calibration Coefficient Use.

INPUT CONVERSIONS MODULE:

```
T390: [W9]
      (((1-$K$308)*(AA71*AK305+AA76*AK307))+((1-$K$309)*((1-
      AA71)*AK305+(1-AA76)*AK307)))*$L$391*$L$392*$L$393*$TE
      RRTGTAVLMULT*(1/$TERRDEFMULT)*@MAX($AA$255^($PWRRCOEFC
      ASKIL*$Q$657),1)


T400: (F1) [W9]
      ((1-$K$308)*$K$253+(1-$K$309)*$S$241)*($L$401-(S403/T3
      98)-(S437/T398))*$L$402*$L$403*$K$253*$TERRTGTAVLMULT*
      (1/$TERRDEFMULT)*@MAX($AA$255^($PWRRCOEFCASKIL*$Q$657)
      ,1)


T422: [W9]
      ((1-K308)*K253+(1-K309)*S241)*L421*L426*L427*TERRTGTAV
      LMULT*(1/TERRDEFMULT)*@MAX(AA255^(PWRRCOEFAIKILS*Q660)
      ,1)


T427: [W9]
      +L421*L433*L434*L435*TERRTGTAVLMULT*(1/TERRDEFMULT)*@M
      AX(AA255^(PWRRCOEFAIDEL*Q663),1)


T432: (F3) [W9]
      ((1-K308)*K253+(1-K309)*S241)*L421*L441*TERRTGTAVLMULT
      *(1/TERRDEFMULT)*@MAX(AA255^(PWRRCOEFAIDISR*Q665),1)


S389: [W9]
      1-$K$396
```

INTERMEDIATE CALCULATIONS MODULE:

```
AA100: [W8]
      @MAX($K$329*@MIN((1-$AA$104^($PWRCOEFIERR-DEF*Q655)),1
      ),0.001)
```

```
AB100: [W8]
      @MAX($INTEL
      ERROR*@MIN((1-$AA$255^($PWRCOEFIERR-ATK*Q654)),1),0.00
      1)


AA259: [W8]
      @MAX($K$329*@MIN((1-$AA$255^(PWRCOEFIERR-ATK*$Q654)),1
      ),0.001)


AB259: [W8]
      @MAX($INTEL
      ERROR*@MIN((1-AB263^(PWRCOEFIERR-DEF*$Q655)),1),0.001)


AA1023: (F5) [W8]
      @MIN(($S$407*$CAMPAIGN LGTH/$AL$307)/($HRS/DAY
      USBLE*60*$AO$254),L623*(AA1020+AA1021))


AA702: (F5) [W8]
      @MIN(($S$408*$CAMPAIGN LGTH/$AL$305)/($HRS/DAY
      USBLE*60*$AO$210),L623*(AA699+AA700))


AA106: [W8]
      @IF(AA104>1,((1-AA102)*Q651*((1-AB104)^$PWRRCOEFTGTAVL
      ))+AA102,AA102)


AB106: [W8]
      @IF(AB104>1,((1-AB102)*Q651*((1-AA104)^$PWRRCOEFTGTAVL
      ))+AB102,AB102)


AA265: [W8]
      @IF(AA263>1,((1-AA261)*Q651*((1-AB263)^$PWRRCOEFTGTAVL
      ))+AA261,AA261)


AB265: [W8]
      @IF(AB263>1,((1-AB261)*Q651*((1-AA263)^$PWRRCOEFTGTAVL
      ))+AB261,AB261)


AA466: [W8]
      +$AA$450*(1-$AA$461)


AB466: [W8]
      +$AB$450*(1-$AB$461)*$AB$462/AB35
```

```
AA786: [W8]
      +$AA$770*(1-$AA$781)*$AA$782

AB786: [W8]
      +$AB$770*(1-$AB$781)/AB35

AA684: [W8]
      +AA672*(1+$AA$682)^($DISMTDLETHCOEF*Q686)*AA692*AB693

AB684: [W8]
      +AB672*(1+AB682)^(DISMTDLETHCOEF*Q686)*AB692*AA693

AA687: [W8]
      +AA675*(1+$AA$682)^($DISMTDLETHCOEF*Q686)*AA692*AB693

AB687: [W8]
      +AB675*(1+AB682)^(DISMTDLETHCOEF*Q686)*AB692*AA693

AA690: [W8]
      +AA678*(1+$AA$682)^($DISMTDLETHCOEF*Q686)*AA692*AB693

AB690: [W8]
      +AB678*(1+AB682)^(DISMTDLETHCOEF*Q686)*AB692*AA693

AA1005: [W8]
+AA993*(1+$AA$682)^($DISMTDLETHCOEF*Q686)*AA1013*AB1014

AB1005: [W8]
      +AB993*(1+AB682)^(DISMTDLETHCOEF*Q686)*AB1013*AA1014

AA1008: [W8]
+AA996*(1+$AA$682)^($DISMTDLETHCOEF*Q686)*AA1013*AB1014

AB1008: [W8]
      +AB996*(1+AB682)^(DISMTDLETHCOEF*Q686)*AB1013*AA1014

AA1011: [W8]
+AA999*(1+$AA$682)^($DISMTDLETHCOEF*Q686)*AA1013*AB1014
```

```
AB1011: [W8]
      +AB999*(1+AB682)^(DISMTDLETHCOEF*Q686)*AB1013*AA1014


ACTIVITY CYCLE MODULE:

AU44: (F3) [W9]
      +$Q$690*($K$504*(1-(1-$AB$100)^$IERRCOEFSURVTM))


AU104: (F3) [W9]
      +$Q$690*($K$504*(1-(1-$AB$259)^$IERRCOEFSURVTM))


AU50: (F3) [W9]
      (($SHADOW DIS-ATK/$BLUE
      MOVEF)+($Q$701*(1/$REDSURVDISCOEF)*@ABS(1-$AO$243)^(1/
      (1-DISENG%AGE-ATK))))*$K$510*($CYC/MVRATK-1)/$CYC/MVRA
      TK


AU110: (F3) [W9]
      (($SHADOWDIS-DEF/$BLUEMOVEF)+($Q$701*(1/$REDSURVDISCOE
      F)*@ABS($AN$262)^(1/(1-$DISENG
      %AGE-DEF))))*$K$510*($CYC/MVRDEF-1)/$CYC/MVRDEF
```

B. Code Changes Affecting Battle Termination and Attrition.

INPUTS MODULE:

```
I241: [W7] 'RED ATTR-RATK

K241: [W8] 0.2

L241: [W8] 0.3

M241: [W9] '%desired/engagement

I242: [W7] 'BLUE ATTR-BLATK

K242: [W8] 0.25

L242: [W8] 0.15

M242: [W9] '%desired/engagement
```

BATTLE CALCULUS MODULE:

```
AI69: [W11] 'Attrit Pref-Blu Atk

AM69: [W7] 'Attrit Pref-Red Atk

AH70: [W9] 'Blu Prefe

AI70: [W11] 'rence on:

AJ70: [W4] 'Blue

AK70: [W9] +L242

AM70: [W7] 'Red

AN70: [W9] +L241

AH71: [W9] 'Red Preference on:

AJ71: [W4] 'Blue

AK71: [W9] +K242

AM71: [W7] 'Red

AN71: [W9] +K241

AH72: [W9] 'Blu Preference on:
```

```
AI72: [W11] 'rence on:

AJ72: [W4] 'Red

AH73: [W9] 'Red Prefe

AI73: [W11] 'rence on:

AJ73: [W4] 'Red

AI415: [W11] '"Break Point" Attrition Values

AI416: [W11] '(considers abil to diseng)

AI417: [W11] 'Blue Attack

AM417: [W7] '

AH418: [W9] 'Red Attrit-Blu Atk

AK418: (P0) U [W9]
      @IF(Q550=0,@MAX(AK73+(AK64*(AK72-AK73)),0.001),@MIN(@M
      AX(AK7
      3+(AK64*(AK72-AK73)),0.001),AK72))

AM418: [W7] '

AH419: [W9] 'Blue Attrit-Blu Atk

AK419: (P0) U [W9]
      @IF(Q550=0,@MAX(AK70+((1-AK64)*(AK71-AK70)),0.001),@MI
      N(@MAX(AK70+((1-AK64)*(AK71-AK70)),0.001),AK71))

AL419: [W12] +AL211*AM214^K611*(1-AK419)

AI421: [W11] 'Blue Defense

AH422: [W9] 'Red Attrit-Blu Def

AK422: (P0) U [W9]
      @IF(Q500=0,@MAX(AN70+((1-AK65)*(AN71-AN70)),0.001),@MI
      N(@MAX(AN70+((1-AK65)*(AN71-AN70)),0.001),AN70))

AH423: [W9] 'Blue Attrit-Blu Def

AK423: (P0) U [W9]
      @IF(Q550=0,@MAX(AN73+(AK65*(AN72-AN73)),0.001),@MIN(@M
      AX(AN73+(AK65*(AN72-AN73)),0.001),AN73))
```

ATTACK ONE ACTIVITY CHANGES:

```
AH200: [W9] +AK204-AL204

AI200: (F2) [W11]
(($AJ$204-@ABS($AK$204-$AL$204)^$K$611)/($AM$204-$AN$204))

AJ200: (F1) [W4] +AK205-AL205

AK200: (F2) [W9]

(($AJ$205-@ABS($AK$205-$AL$205)^$K$611)/($AM$205-$AN$205))

AI201: [W11] 'ATK1 ACTIVITY

AL201: [W12] '        TATK1BBP:

AN201: (F2) [W9]
      @IF(RTARG1B<0,10000,@IF(LNARG1B<1,10000,RAWBBP1))

AO201: [W11] 'hrs

AL202: [W12] 'km      TATK1RBP:

AN202: (F2) [W9]
      @IF(RTARG1R<0,10000,@IF(LNARG1R<1,10000,RAWRBP1))

AO202: [W11] 'hrs   Days

AL203: [W12] 'km/hr   TATK1ACT:

AN203: [W9]
      @MAX(@MIN($AN$200,$AN$201,$AN$202),0.000001)

AO203: (F3) [W11]
      @MAX(AN203/(HRS/DAY USBLE*L613),0.00049)

AH204: (F2) [W9]
      @LN(($AJ$204-@ABS($AK$204-$AL$204)^$K$611)/($AM$204-$A
      N$204))/$AO$204

AI204: (F2) [W11]
      @LN(($AJ$205-@ABS($AK$205-$AL$205)^$K$611)/($AM$205-$A
      N$205))/($AO$205)

AJ204: (F1) [W4] +AM214^K611*(1-AK419)*AL211

AK204: [W9] +AM213*(AL210)^L609

AL204: [W12] (1-(1-AK419)^L609)*(AM214*AL211^L609)

AM204: [W7] +AM214^K611*(AL211)
```

```
AN204: [W9] +AM213^K611*AL210

AO204: [W11] +AO205
```

ATTACK TWO ACTIVITY NOT MODIFIED AT THIS TIME.

DEFEND ACTIVITY CHANGES:

```
AM245: [W7] 'TBBP

AN245: (F2) [W9]
    @IF(RTARGDB<0,10000,@IF(LNARGDB<1,10000,RAWBBPD))

AH246: [W9] +AK249-AL249

AI246: [W11]
    (($AJ$249-@ABS($AK$249-$AL$249)^$K$611)/($AM$249-$AN$2
    49))/($AO$249)

AJ246: (F0) [W4] +AK248-AL248

AK246: [W9]
    (($AJ$248-@ABS($AK$248-$AL$248)^$K$611)/($AM$248-$AN$2
    48))/($AO$248)

AM246: [W7] 'TRBP

AN246: (F2) [W9]
    @IF(RTARGDR<0,10000,@IF(LNARGDR<1,10000,RAWRBPD))

AO246: [W11] '      Days

AK247: [W9]
    @LN(($AJ$248-@ABS($AK$248-$AL$248)^$K$611)/($AM$248-$A
    N$248))/($AO$248)

AL247: [W12]
    (@LN(($AJ$249-@ABS($AK$249-$AL$249)^$K$611)/($AM$249-$
    AN$249))/($AO$249))

AM247: [W7] 'TDEFACT:

AN247: [W9] @MIN(AN245,AN246)

AO247: (F3) [W11]
    @MAX(AN247/(HRS/DAY USBLE*L613),0.00049)
```

```
AH248: [W9]
      (@LN(($AJ$249-@ABS($AK$249-$AL$249)^$K$611)/($AM$249-$
      AN$249))/($AO$249))

AI248: [W11]
      @LN(($AJ$248-@ABS($AK$248-$AL$248)^$K$611)/($AM$248-$A
      N$248))/($AO$248)

AJ248: (F1) [W4]
      +$AM$257^K611*(1-$AK$423)*$AL$254

AK248: [W9]
      +$AM$258*$AL$255^L609

AL248: (F1) [W12]
      (1-(1-$AK$423)^L609)*($AM$257*$AL$254^L609)

AM248: [W7] +$AM$257^K611*$AL$254

AN248: [W9] +$AM$258^K611*$AL$255

AO248: [W11] ($AM$258*$AM$257)^K611
```

APPENDIX D

BASE CASE MODEL INPUTS FOR SENSITIVITY ANALYSIS

TERRAIN FEATURES IN ZONE (2 Screens)

COVER	GRADIENT	MOVEMENT RATE coeff.	DEFENSE STRENGTH coeff.	TARGET AVLBTY coeff.	FRACTION OF ZONE
Clear	Flat	0.90	1.13	1.00	0.06
Mixed	Flat	0.83	1.24	0.90	0.05
Forest	Flat	0.64	1.30	0.65	0.06
Urban	(N/A)	0.64	1.73	0.30	0.17
Clear	Rolling	0.87	1.30	1.00	0.09
Mixed	Rolling	0.78	1.40	0.90	0.04
Forest	Rolling	0.55	1.46	0.60	0.08
Clear	Hills	0.64	1.40	0.95	0.04
Mixed	Hills	0.60	1.51	0.85	0.07
Forest	Hills	0.46	1.57	0.50	0.10
Clear	Broken	0.60	1.57	0.85	0.05
Mixed	Broken	0.46	1.62	0.75	0.06
Forest	Broken	0.37	1.73	0.55	0.08
Clr/Mixd	Marsh	0.37	1.40	0.95	0.03
Jungle	Marsh	0.18	1.40	0.90	0.00
Clear	Mountains	0.28	1.84	0.75	0.01
Mixed	Mountains	0.18	2.05	0.40	0.01
Desert	Flat/Rolling	0.83	1.27	1.00	0.00
Desert	Hills/Mtns	0.28	1.51	0.80	0.00
Arctic	Flat/Rolling	0.37	1.51	1.00	0.00
Arctic	Hills/Mtns	0.18	1.94	0.80	0.00
Tropical	Flat/Rolling	0.64	1.40	0.80	0.00
Tropical	Hills/Mtns	0.37	1.62	0.40	0.00

RED THREAT AND SCENARIO (ZONE GEOGRAPHY AND FORCE SIZE)

```
ZONE WIDTH          750         km
ZONE LENGTH         300         km

#CHOKE AREAS        0.00        # areas where traffic is confined
CHOKEAR FRONTG      0.00        Average choke area width (km)
CHOKEAR DEPTH       0.00        Average choke area depth (km)
HRS/DAY USBLE       24.0        hrs/day usable for operations
BLUE WARNING        2.00        days

# RED MVR           30.0        # Red maneuver units (rmvrs)
# FRNT LN DIVS      24.0        # rmvrs in front line
# RED HQs            7.0        # Red Headquarters (HQs)
# RED ENG UNITS      7.0        # Red engineer units

% RMVRS-ATK         0.75        % rmvrs assigned atk mission
RED DIV SEPRTN      25.0        Average distance between rmvrs (km)
RMVR AGGRSV-ATK     0.80        Dist toward enemy/total dist moved
RMVR AGGRSV-DEF    -0.05        Dist toward enemy/total dist moved
                                  (+1.0=forw; -1.0=away; 0=static)
```

BLUE SUCCESS CRITERIA AND ZONE-LEVEL POLICY (2 screens)

SUCCESS CRITERIA (automatically met by MOSCOW)

```
RED PEN LIMIT                 60 km Red allowed to penetrate zone
RED SURVIVORS                8.0 # rmvrs allowed to survive
MAXPEN PRE-INT              10.0 km max pen before must eng Red
```

TIME OBJECTIVE (criterion for evaluating performance of concept)

```
DELAY                        3.0 campaign-days added by Blue operns
```

OPERATIONAL-LEVEL INPUTS THAT DESCRIBE BLUE'S WARFIGHTING CONCEPT

DEPLOYMENT

```
FORW BNDRY                   0.0 km to border              --
REAR BNDRY                    30 km to border              --
%ATKOPS-LINEAR              0.50 % Blue atks using linear operations
%of ZONEW DEFD              1.00 % zone frontage covered by Blue
```

MVR ENGAGEMENT AGGRESSIVENESS

```
MVR AGGRSV-ATK              0.50 Dist toward enemy/total dist moved
MVR AGGRSV-DEF             -0.20 Dist toward enemy/total dist moved
                                   (+1.0=forw; -1.0=away; 0=static)
```

MVR MISSION ASSIGNMENTS

%MVRs-ATK KILS	0.20	% rmvrs to be killed by atk mvrs
%MVRs-DEF KILS	0.80	% rmvrs to be killed by def mvrs (remaining MVRs assumed in RSV)

HQs AND ENGINEERS

# HQs AVAIL	8.0	# Blue HQs in zone
HQ SPAN-#MVRs	5.0	# mvrs controllable by Blue HQs
HQ RADIUS-KM	75.0	Max dist an HQ can control an mvr
# ENG UNITS AVAIL	10.0	# Blue engineer units in zone

{Alt+L}LIMITS OF BLUE FORCES AND RESOURCES FOR ZONE (2 screens)

CATEGORY	RESOURCE	AVAIL.	
TOTAL MVR AVAILABLE	INITIAL	21.80	mvrs
MAXIMUM CASUALTIES	TOTAL CASUALTY	250000	pers
	AVG CASLTY/DAY	5000.0	pers/day
REPLACEMENT STOCKS AVAILABLE	PERSONNEL	200000	pers
	VEHICLES	12000	veh
	AMMO (TONS)	7.0E+05	tons
	POL (TONS)	5.0E+06	tons
	OTHER (TONS)	1.0E+05	tons
	LIFT (TONS)	1.5E+06	tons
DAILY REPLACEMENTS AVAILABLE	PERSONNEL	4000.0	pers/day
	VEHICLES	400.0	veh/day
	AMMO (TONS)	2.0E+04	tons/day
	POL (TONS)	4.0E+05	tons/day
	OTHER (TONS)	4.0E+03	tons/day
	LIFT (TONS)	1.1E+04	tons/day
SUPPLY & HQs AVAILABLE	SUPPLY VEHICLES	100000	# vehicles
	TOLERANCE LEVEL:	110%	Required/available

MANEUVER UNIT DESCRIPTION AND OPERATIONAL POLICY (7 screens)

	Red	Blue	
SIZE OF MANEUVER UNIT (MVR)			
TECH/ORG			
VEH/MVR	1042	1399	# vehicles per maneuver unit
GENERAL			
TECH/ORG			
DISENG %AGE-ATK	NA	0.50	% of engagement
DISENG %AGE-DEF	NA	0.50	% of engagement
% NON-MV/CBT	0.66	NA	%time not moving or fighting
POLICY & NORMS			
TAC PWR-ATK	1.25	1.25	Ratio: Attack to defend combat power
RED ATTR-BLATK	0.13	0.28	%desired/engagement
BLUE ATTR-RATK	0.30	0.15	%desired/engagement
RED ATTR-RATK	0.20	0.30	%desired/engagement
BLUE ATTR-BLATK	0.25	0.15	%desired/engagement
MOBILITY			
TECH/ORG			
MVMT/HR-ADMIN	12.0	10	km/hr
MVMT/HR-BATTL	5.0	5	km/hr
VEH DASH SPD	65.8	69	km/hr
VEH BRKDWNS	0.060	NA	% vehicles that breakdown per day
POL CONS/KM	NA	0.8	gals/km
TIME-CHNG FORM	20.0	20	minutes to change formation type
POLICY & NORMS			
%MVMT-ADM FORM	0.33	0.33	% of mvmt time in adm. formation
TAC STA PD-ATK	0.75	1.75	minutes stationary when attacking
TAC STA PD-DEF	4.00	1.80	minutes stationary when defending
DIS/TAC MV-ATK	450.0	175.0	meters moved per dash in attack
DIS/TAC MV-DEF	200.00	80.0	meters moved per dash on defense
IF %OPNL MOVE	0.80	0.80	IF aggresiveness as % of DF aggrss.
LETHALITY			
TECH/ORG			
% FIRERS-ADMIN	0.25	0.25	% veh able to fire in adm. formation
% FIRERS-BATTL	0.65	0.70	% veh able to fire in btl. formation
MAX IF RATE-S	5.0	5.00	max rnds/min of IF while stationary
MAX IF RATE-M	5.0	5.00	max rnds/min of IF while moving
MAX DF RATE-S	3.7	3.40	max rnds/min of DF while stationary
MAX DF RATE-M	2.4	2.08	max rnds/min of DF while moving
IF RANGE-MAX	27.00	20.00	km
IF RANGE-MIN	0.50	0.50	km
DF RANGE-MAX	4.00	4.17	km
DF RANGE-MIN	0.70	0.07	km
HITS/RND-S/S	0.56	0.56	P(hit/rnd): sta DF, sta tgt @min rng

HITS/RND-S/M	0.47	0.47	P(hit/rnd): sta DF, mov tgt @min rng
HITS/RND-M/S	0.29	0.29	P(hit/rnd): mov DF, sta tgt @min rng
HITS/RND-M/M	0.19	0.19	P(hit/rnd): mov DF, mov tgt @min rng
HIT DEGRD-MAXR	0.62	0.62	Degradation of P(hit/rnd) at max rng
KILLS/HIT	0.50	0.47	Prob. of vehicle kill given hit
ANTI-PERS COEF	0.30	0.30	Pr. dismtd infy kill given veh kill
IF HITS/R COEF	0.33	0.33	Degradation of P(hit/rnd) for IF
POLICY & NORMS			
ACT IF RATE-S	1.50	1.50	actual IF rnds/min while stationary
ACT IF RATE-M	1.50	1.50	actual IF rnds/min while moving
ACT DF RATE-S	0.92	0.92	actual DF rnds/min while stationary
ACT DF RATE-M	0.27	0.23	actual DF rnds/min while moving
ACT IF RANGE-HI	25.00	20.00	km
ACT IF RANGE-LO	0.50	0.50	km
ACT DF RANGE-HI	3.67	3.55	km
ACT DF RANGE-LO	0.06	0.07	km
IF DIST-FLOT-HI	8.00	8.00	km
IF DIST-FLOT-LO	5.00	5.00	km
DF DIST-FLOT-HI	1.57	1.76	km
DF DIST-FLOT-LO	0.14	0.10	km
% FIRERS DF	0.81	0.80	% veh firing in DF mode
% PERS DISMTD	0.10	0.23	% personnel acting as dismtd infy
VEH DIS%-DEF	0.04	0.01	max dis betw veh as % of avg range
DESIRD FRNTAGE	13.00	21.00	km
MISC LETH MU-AT	1.00	1.00	x Friendly lethality
MISC LETH MU-DE	1.00	1.00	x Friendly lethality
% ATKRS-1st ECH	0.67	NA	% of atk veh in 1st ech
VULNERABILITY			
TECH/ORG			
HARDNESS-FRONT	1.00	1.00	x hardness assumed in enemy P(kill)
HARDNESS-SIDE	1.00	1.00	x hardness assumed in enemy P(kill)
CONCLMT-ADMIN	0.16	0.15	% veh concealed from enemy
CONCLMT-BATTL	0.35	0.35	% veh concealed from enemy
MAX ATTR/DAY	1.00	1.00	% pers attr/day before unit breaks
BREAKPOINT	1.00	1.00	% pers cum attr before unit breaks
POLICY & NORMS			
SHADOW DIS-ATK	NA	8.00	km
SHADOW DIS-DEF	NA	5.00	km
DEFENSE PREP%	NA	0.50	% of max preparations
VEH DIS-ATK	50.0	50.0	min dist betw veh--m
MISC VULN MU-A	1.00	1.00	x Enemy lethality
MISC VULN MU-D	1.00	1.00	x Enemy lethality
C3IEW			
TECH/ORG			
ACQ TIME-S TGT	180.0	180.0	secs. reqd to acquire stationary tgt
STGT#SHOTS-ACQ	1.50	1.50	# of tgt's shots reqd to acq sta tgt
C-3 ERROR	0.05	0.05	min % errors in C-3 system
C-3 REGEN/DAY	0.01	0.02	daily reduc. in C-3 error from regen
MAX C-3 ERR	0.40	0.20	max % errors in C-3 system
INTEL ERROR	0.03	0.03	min % errors in Intel system

EW EFFNESS	1.75	1.50	x Blue/red C-3 err due to EW
ATK PREP&RECOV	10.00	NA	Prep&recov time as mult of atk time
DEF PREP&RECOV	4.00	NA	Prep&recov time as mult of def time

BASIC LOAD & LOGISTICS

TECH/ORG			
PERS/VEH	7.87	7.14	passengers and crew per veh
AMMO/VEH	37	33	rounds per veh
POL/VEH	NA	500	gals POL per veh
OTH/VEH	NA	200	lbs. other resources per veh
VEH WEIGHT	NA	25	tons / veh weight
PERS WEIGHT	NA	200	lbs./person
AMMO WEIGHT	52.3	53	lbs./round
POL WEIGHT	NA	8.5	lbs./gallon
PERS REGEN/DAY	NA	200	# non cbt casualties recoverable/day
VEH REGEN/DAY	5	20	# veh losses recoverable/day
CAS REGEN COEF	NA	0.33	Cbt cas recov per non cbt cas recov
POLICY & NORMS			
%REPL/ATK CYC	0.30	0.30	% veh losses repl. by next atk engmt
%REPL/DEF CYC	0.30	0.30	% veh losses repl. by next def engmt
DIS-EXCHPT-DEF	NA	3.00	km from def engmt to supply exch. pt
DIS-EXCHPT-ATK	NA	20.0	km from atk engmt to supply exch. pt
% REST	NA	0.25	% of time spent resting
%REPRBL LOSS-M	NA	0.08	% of losses repairable by mvr
%REPRBL LOSS-T	NA	0.50	% of losses repairable by theater
% REPRD-M	NA	0.20	% of reprbl losses reprd by mvr
LOAD RATE	NA	14000	tons supplies loaded/hr
SUPP VEH MOVEF	NA	150	km/day that a supply veh can move
CAP/SUPP VEH	NA	5.0	tons capacity per supply veh
CAP DEGRDN/KM	NA	0.001	tons cap degrdn per km total dist

FIRE, AIR AND ENGINEER SUPPORT ALLOCATION (5 screens)

	Red	Blue	
CLOSE AIR SUPPORT (PLANES AND HELOS)			
TECH/ORG			
STARTING CAS	684	688	initial CAS aircraft
SORTIES/DAY	2.00	2.50	sorties/day
AIR ATTRITION	0.07	0.04	Attrition rate per sortie
TONS ORD/S	6.00	8.00	tons ordnance per sortie
HITS/TON	0.30	0.30	# vehicles hit per ton of ordnance
KILLS/HIT	0.90	0.90	Prob. vehicle killed given hit
PERCENTAGE ALLOCATION			
% ATTK	0.10	0.30	% of aircraft supporting atk mvrs (remainder support defd MVRs)

HEADQUARTERS ARTILLERY

TECH/ORG			
TONS/D/HQ	4E+03	3.6E+03	tons ammo fired per day per HQ
HITS/TON	0.20	0.20	veh hits per ton ammo fired
KILLS/HIT	0.50	0.50	Prob. vehicle killed given hit
TONS SUPPD/T	0.60	0.60	tons enemy HQ fire suppressed/ton

PERCENTAGE ALLOCATION			
% ATTK	0.10	0.10	% of HQs supporting attk mvrs
%COUNTERHQ	0.10	0.30	%of HQs in counterfire against HQs (remainder support defd MVRs)

ENGINEERS

TECH/ORG			
DEL/D/ENG	NA	0.50	Rmvr-days delay/Blue engnr-unit-day
ACCEL/ENG	0.30	NA	Rmvr-days accel/Red engnr-unit-day

AIR INTERDICTION

TECH/ORG			
INITIAL AI	569	569.50	initial AI aircraft
SORTIES/DAY	1.50	2.00	sorties/day
AIR ATTRITION	0.15	0.10	Attrition rate per sortie
TONS ORD/S	6.00	8.00	tons ordnance per sortie

AI ATTRITION MISSION

TECH/ORG			
HITS/TON	0.40	0.75	# vehicles hit per ton of ordnance
KILLS/HIT	0.90	0.90	Prob. vehicle killed given hit

AI DELAY MISSION

TECH/ORG			
HITS/TON	0.25	0.50	target hits/ton of ordnance
KILLS/HIT	0.45	0.50	Prob. target killed given hit
DELAY/KILL	180.00	150.00	mins. mvr delay per target killed

AI DISRUPTION MISSION

TECH/ORG			
C3 ERR/TON	0.002	0.005	Incr. in mvr C3 error/ton ordnance

AI COUNTER HQ MISSION

TECH/ORG			
TONS SUPPD/T:	0.75	0.75	tons enemy HQ fire suppressed/ton

AI SUPPLY MISSION

TECH/ORG

S VEH HITS/TON	2.00	NA	Supply veh hits per ton ordnance
S VEH KILS/H	0.50	NA	Prob. supply veh killed given hit
VEH REIN HITS/T	NA	4.00	Reinforcement veh hits/ton ordnance
VEH REINF K/H	NA	0.80	Prob. reinf vehicle killed given hit

POLICY AND NORMS: PERCENTAGE ALLOCATION

% ATTRIT	0.05	0.20	% AI sorties assnd attrition mission
%DELAY	0.10	0.10	% AI sorties assigned delay mission
%DISRUPT	0.40	0.50	% AI sorties assigned disrpt mission
%COUNTER HQ	0.45	0.20	% AI sorties assnd counterHQ mission
			(remainder assigned supply mission)

RESOURCE CONSUMPTION COEFFICIENTS

ACTVTY	%Crit pa	%Unit-tm	Veh	Pers	Ammo	POL	Other	
PRE	1.00	1.00	0.020	0.30	0.33	0.50	25.0	PRE
S&R	1.00	1.00	0.040	0.40	0.75	0.75	25.0	S&R
DEL	1.00	1.00	0.010	0.20	0.33	0.50	25.0	DEL
MWR	1.00	1.00	0.060	0.30	1.00	1.00	25.0	MWR
ATK1	1.00	1.00	0.080	0.60	1.00	1.00	25.0	ATK1
ATK2	1.00	1.00	0.080	0.60	1.00	1.00	25.0	ATK2
DEF	1.00	1.00	0.080	0.60	1.00	1.00	25.0	DEF
DIS	1.00	1.00	0.040	0.40	1.00	1.00	25.0	DIS
RCL	1.00	1.00	0.040	0.40	1.00	1.00	25.0	RCL
RCST	1.00	1.00	0.030	0.10	1.00	0.50	25.0	RCST
MTX	1.00	1.00	0.020	0.15	0.75	0.85	25.0	MTX
LOD	0.00	1.00	0.005	0.07	0.33	0.50	25.0	LOD
RPR	0.33	1.00	0.005	0.07	0.33	0.50	25.0	RPR
RES	1.00	1.00	0.005	0.07	0.33	0.50	25.0	RES
MTS	1.00	1.00	0.040	0.15	0.75	0.85	25.0	MTS
MXC	1.00	1.00	0.040	0.15	0.75	0.85	25.0	MXC
UNL	1.00	1.00	0.005	0.07	0.33	0.50	25.0	UNL
Units	%of a	%mvr	%vehs/d	%pers/v	%ammo/v	%act(mv)	lbs oth/ pers/day	

CONSTRAINTS ON BLUE AND RED UNIT ACTIVITIES

ACTIVITIES IN CYCLE		SPECIAL CONSTRAINTS:	
PRE	Prepare defenses		
S&R	Survey and reconnoiter	MIN NUMBER OF BLUE MVRs	0
DEL	Delay for higher echelon orders	MAX CUM CASUALTIES (%)	0
MWR	Move to weapon range (1st contact	MAX CBT PWR RATIO:R ATK	0
ATK1	Attack--1st phase (1 Red unit)	MAX CBT PWR RATIO:B ATK	0
ATK2	Attack--2nd phase (reinf. Red)	MAX PEAK CASUALTIES/DAY	0.00%
DEF	Defend	%OF ZONE FRONTAGE DEFN'D	0%

DIS	Disengage (to shadow distance)	ATKRS CHOOSE ENGMT BRKOFF 0
RCL	Re-close (from shadow distance)	
RCST	Reconstitute (unit cohesion)	If special constraints
MTX	Move to exchange point	are set to zero, they will not
LOD	Load supplies	affect other equations. If set
RPR	Repair (vehicles and personnel)	to a number, that value will be
RES	Rest	used. For the three "max" con-
MTS	Move to standby position	straints, setting them to a
MXC	Move cross-country in own rear	very large value will cause
UNL	Unload supplies	other, more binding constraints
TOT	Total--all activities in cycle	to be employed instead.

MVR/ ACTIVITY	% of Total Cycle		Time in days	
ATK CONSTRAINTS	Constraint	Unconstrained	Constrained	Unconstrained
PRE	0.0%	0.0%	0.00	0.00
S&R	0.0%	1.4%	0.00	0.03
DEL	0.0%	1.3%	0.00	0.02
MWR	0.0%	3.2%	0.00	0.06
ATK1	0.0%	2.3%	0.00	0.04
ATK2	0.0%	0.0%	0.00	0.00
DEF	0.0%	0.0%	0.00	0.00
DIS	0.0%	8.9%	0.00	0.16
RCL	0.0%	5.2%	0.00	0.10
RCST	0.0%	0.8%	0.00	0.01
MTX	0.0%	15.1%	0.00	0.28
LOD	0.0%	1.5%	0.00	0.03
RPR	0.0%	12.7%	0.00	0.23
RES	0.0%	24.9%	0.00	0.46
MTS	0.0%	22.5%	0.00	0.41
MXC	0.0%	0.0%	0.00	0.00
UNL	0.0%	0.0%	0.00	0.00
TOT	NA	NA	0.00	1.84

MVR/ ACTIVITY	% of Total Cycle		Time in days	
DEF CONSTRAINTS	Constrained	Unconstrained	Constrained	Unconstrained
PRE	0.0%	47.0%	0.00	1.04
S&R	0.0%	1.1%	0.00	0.02
DEL	0.0%	1.1%	0.00	0.02
MWR	0.0%	0.0%	0.00	0.00
ATK1	0.0%	0.0%	0.00	0.00
ATK2	0.0%	0.0%	0.00	0.00
DEF	0.0%	0.8%	0.00	0.02
DIS	0.0%	5.4%	0.00	0.12
RCL	0.0%	0.0%	0.00	0.00
RCST	0.0%	0.7%	0.00	0.02
MTX	0.0%	1.9%	0.00	0.04
LOD	0.0%	1.6%	0.00	0.04
RPR	0.0%	14.3%	0.00	0.32
RES	0.0%	25.0%	0.00	0.55
MTS	0.0%	1.2%	0.00	0.03
MXC	0.0%	0.0%	0.00	0.00
UNL	0.0%	0.0%	0.00	0.00
TOT	NA	NA	0.00	2.21

```
{Alt+K}            CALIBRATION COEFFICIENTS

                 MANDATORY CALIBRATION COEFFICIENTS

                          VALUE                    CALCULATION
                          ("X")                     AFFECTED
       Engagement Phenomena

EXPONENT OF NUMERICAL      2.00                    Engagement
  STRENGTH IN LANCHESTER EQN.                       Duration
 (Note: 1/X =      0.50 )

ENGAGEMENT TEMPO           1.00                    Engagement
 MULTIPLIER                                         Duration
 (Note: If X < 1, engagements slow down.)

       MVR Capabilities

HOURS/DEFENSE PREP. %      0.50                    Time (PRE)

BASELINE % REST            0.25                    Mobility, Lethality

MAXIMUM FIRE SUPPORT:      1.00                    Lethality
 X * MVR ORGANIC LETHALITY

       Frontage of Attacking MVRs

% OF RED VEHICLES IN       0.30 Red                Attacking MVRs'
 LEAD OF ATTK FORMATION                             frontage; Max TAC FR

% OF BLUE VEHICLES IN      0.30 Blue               Attacking MVRs'
 LEAD OF ATTK FORMATION                             frontage; Max TAC FR

       Rear Area Security Planning Factors

PERSONNEL / KM^2           0.02 Red                RMVRs withheld for SEC.

 REQUIRED FOR SECURITY

PERSONNEL / KM^2           0.01 Blue               Blue SEC MVRs required
 REQUIRED FOR SECURITY

                 OPTIONAL CALIBRATION COEFFICIENTS

             COEFFICIENT                                             USE
     -------------------------    VARIABLE                            X?
     VARIABLE AND          VALUE    DIRECTLY          CALCULATION
Yes=1
       RELATION           ("X")   AFFECTED          AFFECTED        No= 0
```

Concentration and Dispersion Effects

TAC PWR R ^ X		9.00	Availability (as a target)	Enemy Lethality	1
TAC PWR R ^ X	ATK Case	1.0	Enemy Intel. error	Availability (as a target)	1
	DEF Case	1.0			1
TAC PWR R ^ X		0.5	CAS Vehicle kill rate	Vehicles killed per CAS sortie	1
TAC PWR R ^ X		0.5	AI Vehicle kill rate	Vehicles killed per AI sortie	1
TAC PWR R ^ X		0.5	AI Delay	MVR Movement rate	1
TAC PWR R ^ X		0.5	AI Disruption	C-3 error	1
EXCESS DEFENSE FRONTAGE ^ X		1.5	Terrain Defense Multiplier	Attacking MVRs' Lethality	1
(X * BLUE DEPTH)		3E-03	Red Breakdown Rate	# of RMVRs to be killed by Blue MVRs	1

Topographical Effects

TERR MVMT MULT ^ X	1.0	% of Zone Usable	MVR frontage on Defense	1
1-((1-TERRAIN AVAIL. MULTIPLIER) / X)	2.5	Attacker Avail. (as a target)	Defending MVRs' Lethality	1

Dismounted Infantry Effects

%PERS DISMTD ^ X	1.0	Personnel Hits	Personnel Casualties	1
%PERS DISMTD ^ X	0.50	DF Lethality	MVR Lethality	1

C-3I Effects

(1 + INTEL ERR) ^ X	1.00	Time (S&R)	Total cycle time	1
(MVRs/HQ) ^ X	1.0	Time (DEL)	Total cycle time	1
HQ BURDEN ^ X	0.5	Time (DEL)	Total cycle time	1
HQ BURDEN ^ X	1.0	Operational C-3 Error	MVRs Required	1

Engagement Recovery Effects

((1/(1-%RED SURV))^(1/ DISENGAGE%)) * (1/X)	8.00 Time (DIS)	Total cycle time	1
(X/(%BLUE SURV * (1-C3 ERROR))*TIME-FORMN CHANGE)	0.5 Time (RCST)	Total cycle time	1

Campaign Intensity Effects

(%REST ACTUAL/BASELINE % REST) ^ X	1.00 Blue Lethality, Mobility	Blue Lethality, Mobility	1
(((RED %NON-MOVE/CBT) / BLUE %NON-M/C)) ^ X	1.00 RED C-3 Error	Red Mobility and Lethality	1

SEED VALUES FOR STARTING MODEL ITERATIONS

SEED MVRs	10.0	Number of blue MVRs on first iteration

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Thesis
H20453 Hanson
c.1 Calibration coefficient
use and value selection
guidance for the MOSCOW
land combat model.